Abrasive-disk dehullers in Africa

from research to dissemination

Michael W. Bassey O.G. Schmidt

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Michael W. Bassey
O.G. Schmidt

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Postal Address: PO Box 8500, Ottawa, Ontario, Canada K1G 3H9

Bassey, M.W.
Schmidt, O.G.

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Abstract — Résumé — Resumen

Abstract — Recent droughts in the Sahel and in eastern and southern Africa have increased the urgency with which national policymakers are considering drought-resistant crops. National systems for agricultural research in many African countries have strengthened their programs to improve sorghum and pearl millets. A food crop, however, only becomes food when it is actually consumed. Efforts to increase food production must, therefore, be matched by corresponding research on food after harvest. The absence of appropriate dehulling equipment, especially for small grains, has often been cited as a reason for past national neglect of these cereals.

This publication reviews the development of small-scale, inexpensive, versatile abrasive-disk dehullers in Africa. The rural deployment of mechanical dehullers offers an opportunity to enhance national cereal self-sufficiency and to increase use of the productive capacity of the low-rainfall areas of Africa.

The topics discussed in detail include the need to understand traditional food habits and preferences; the scope for applying small dehullers in Africa; detailed technical descriptions of various dehuller designs and criteria to be considered in a design process; important grain characteristics as they relate to dehulling and the effect of the dehuller's abrasive agent on the grain; installation and operation of some typical, rural, small-scale milling systems; and the process of introducing technology as one moves from applied research to applying the results.

Résumé — Par suite des récentes sécheresses au Sahel et en Afrique orientale et australe, il est devenu encore plus urgent que les auteurs de politiques nationales se penchent sur la question des cultures résistant à la sécheresse. Les systèmes nationaux de recherche agricole de nombreux pays africains ont renforcé leurs programmes visant à améliorer les cultures de sorgho et de millet à chandelle ou millet d'Afrique. Une récolte ne peut cependant être dite alimentaire qu'à partir du moment où elle est réellement consommée. Les mesures ayant pour but d'accroître la production de nourriture doivent donc s'accompagner de recherches correspondantes sur les aliments après les récoltes. On cite souvent l'absence d'équipement de décorticage approprié, particulièrement pour les céréales de plus petites dimensions, comme l'une des raisons expliquant que l'on ait négligé ces cultures dans le passé.

Cette publication fait l'historique de la mise au point de décortiqueurs à disques abrasifs de petites dimensions, peu coûteux et polyvalents en Afrique. Leur utilisation en milieu rural donne aux pays concernés l'occasion d'accroître leur autosuffisance en matière de céréales et d'exploiter davantage la capacité de production des régions à faible pluviosité en Afrique.

Voici les sujets qui sont abordés en détail dans la publication : l'importance de comprendre les habitudes et préférences alimentaires traditionnelles ; les possibilités d'utilisation des petits décortiqueurs en Afrique ; la description technique détaillée de divers modèles de décortiqueurs et les critères à prendre en considération dans leur conception ; les caractéristiques importantes des céréales aux fins de décorticage et les effets des agents abrasifs sur les céréales ; l'installation et le fonctionnement de certaines meuneries de petite échelle typique des milieux ruraux ; et la transition entre la recherche appliquée et l'introduction de la technologie qui en découle.

Resumen — Recientes sequías en la región del Sahel y en las regiones orientales y del sur de Africa han urgido a los formuladores de políticas a tener en cuenta los cultivos resistentes a las sequías. Sistemas nacionales para la investigación agrícola en muchos países africanos han fortalecido sus programas para mejorar el sorgo y los mijos perlados. Sin embargo, un cultivo solamente se convierte en alimento cuando se consume. Los esfuerzos para incrementar la producción de alimentos deben ir acompañados de investigaciones sobre el alimento después de la cosecha. La ausencia de equipo adecuado de descascaramiento, sobre todo para granos pequeños, ha sido mencionada a menudo como causa de que a escala nacional se haya descuidado el cultivo de estos cereales en el pasado.

Esta publicación analiza el desarrollo en Africa de descascaradores de disco abrasivo pequeños, baratos y versátiles. El empleo en áreas rurales de descascaradores mecánicos ofrece oportunidad de mejorar el autobastecimiento nacional de cereales y aumentar el uso de la capacidad productiva de las áreas con escasa precipitación pluvial en Africa.

Los tópicos discutidos en detalle incluyen: la necesidad de comprender hábitos y preferencias alimentarios tradicionales; el espacio abierto para la aplicación de los descascaradores pequeños en Africa; descripciones técnicas detalladas de los diferentes diseños de descascaradores y criterios que se deben considerar al diseñarlos; características importantes de los granos relacionados con el descascaramiento y el efecto que tiene el agente abrasivo descascarador sobre el grano; instalación y operación de algunos pequeños sistemas de molienda típicos del área rural; y proceso de introducción de tecnología al pasar de la investigación aplicada a la utilización de los resultados.

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Michael W. Bassey
O.G. Schmidt

Foreword

The International Development Research Centre (IDRC) has, over the past 15 years, supported several projects in Africa aimed at developing dehullers for grains, the staple foods of the populations in several semi-arid regions. These efforts have culminated in the development of abrasive-disk dehullers that can effectively reduce the tasks of women in both rural and urban areas. Past experience has, however, indicated that, to use the available results satisfactorily, people from various disciplines need access to information on certain topics of relevance to grain milling. The authors have attempted in this book to fill this gap.

This book provides an informative compilation of the technical aspects of abrasive-disk dehullers in the context of rural Africa. It summarizes the results of past applied research, offers pragmatic guidance to the applied researcher starting work on grains processing, and emphasizes the importance of research-for-development. Various groups of people, from social scientists and development workers, through policymakers, to technologists and manufacturers, should find it informative. The book can be viewed as a technical companion to the earlier publication, *An End to Pounding* (Eastman 1980), and to the film of the same title.

Although the book emphasizes processing small grains in Africa, much of its content is applicable to other continents where the manual processing of sorghum, millet, a wide variety of pulses, maize, barley, and quinoa is a time-consuming daily task.

Edward J. Weber, Associate Director
Agriculture, Food and Nutrition Sciences Division
International Development Research Centre

CHAPTER 1
INTRODUCTION

The cereal grains sorghum and millet have a vital role in helping to feed Africa. These small, drought-resistant grains are being given increasing importance by African policymakers who are concerned with national food policy, cereal self-sufficiency, and household food security. The overwhelming focus of policy, extension, and agricultural research has, to date, been on increasing and improving the production of these cereals. However, major constraints to increasing production occur after harvest in the relatively neglected field of postproduction research.

The absence of appropriate dehulling equipment has often been cited as a reason for national neglect of these important cereals in the past. Recently, a few African and Canadian scientists have conducted applied research on a technology intended to improve the processing, and thus increase the utilization, of sorghum and millet. The research has taken place largely since 1972, and has constituted a postproduction "push" to complement the "push" for increased grain production. This research has resulted in simple, small-scale dehullers that are now being more widely disseminated in several countries.

This book presents a synthesis of technical aspects of dry abrasive-disk dehullers in the context of rural Africa. It describes some of the applied research that has been done, offers the basic technical information required by the applied researcher starting work on small-grains processing, and stresses the importance of research-for-development and of food-systems thinking.

This chapter identifies more closely the aim of the book and its intended readership, presents the context of the food problem for which the dehuller is a potential solution, and summarizes the content of subsequent chapters.

AIM OF THE BOOK

The book draws on the experiences and lessons learned by applied researchers in addressing the processing problems of the producer and consumer of sorghum and millet. The research that has been undertaken reflects a systematic process of the application of science and inquiry. The process began with identifying the precise nature of the food problem, proceeded to the generation of potentially useful hardware technologies, and tested the appropriateness of the new solution within the existing food system. The hardware-development phase is now nearing completion, and the efforts of applied science are being directed to disseminate the technology to potential users.

Applied researchers in other countries now wish to determine how and whether the dry abrasive-disk dehullers suit the unique problems of their respective

semi-arid areas. The book is intended to provide these new researchers with an understanding of the breadth and complexity of the interrelated issues that they will face in seeking to solve problems in the indigenous grain (and grain legume) food system.

Thus, the book is aimed primarily at applied researchers, and especially those who seek to address the processing and utilization bottlenecks faced by rural (and urban) people with sorghum, pearl (or bulrush) millet, and certain grain legumes. These applied researchers are involved with some aspect of the food systems of the drought-resistant grains and grain legumes, have a mandate to intervene in these food systems with policy or with technology to improve rural (and urban) life, and seek an overview of the work accomplished to date by their African and Canadian research colleagues.

Those in the primary audience for this book are active across a wide array of sectors: rural development, small-industry development, planning and implementing national food-policy or food-security strategies, appropriate technology, technology policy, nutrition intervention, grain marketing, food processing, and agricultural research. Members of this primary readership may have been trained in some of the following disciplines: mechanical or agricultural engineering, nutrition, food processing, rural economy or sociology, agricultural extension, cereal science, or the general field of agriculture.

The members of our target audience are relatively isolated because, in Africa, they are few. They do not have ready access to the formal and informal scientific literature, either in their own countries or in other sub-Saharan countries. These readers may have heard about the existence of small-scale dehulling machines, but the information available has not been systematically presented or widely shared.

The book is a synthesis of many reports written by applied researchers whose work remained largely unreported in the formal technical literature, and of our knowledge of research concerned with the development and introduction of abrasive-disk dehullers. Many of the references cited are, therefore, from the gray literature — a literature that is often incomplete, fragmented, lacks professional editing and presentation, but that forms an important bridge between the scope of practical rural development and the narrowly focused technical journals of the industrialized world.

To avoid repeating previously published material, this book should be viewed as an augmentation to *An End to Pounding* (Eastman 1980), the contents of which remain relevant especially the sections dealing with business aspects, economic break-even point, and management systems.

Context of the Food Problem in Africa

Food production in Africa occupies the energies of some 80% of the population, mostly subsistence farmers, who cultivate small plots of land. Much of the food produced remains on the homestead and is used to satisfy the family's year-round needs. The sale of surplus production can provide the rural dweller with cash for school fees, clothing, and manufactured goods while, at the same time, feeding the rapidly increasing number of urban dwellers.

Importance of sorghum and millet

In 1981, sorghum and millet accounted for 28% of cereal production in Africa (maize, wheat, and rice accounting for 43, 11, and 11%, respectively). Yet, sorghum and millet constitute a very small portion of the cereals bought and distributed by official grain-marketing agencies. Sorghum is Africa's second most important cereal crop (after maize); on a worldwide basis, however, it ranks fifth (after wheat, maize, rice, and barley). Tables 1 and 2 present the 1981 production figures for sorghum and millet and reflect a nondrought year. These crops are well adapted to the semi-arid regions (Fig. 1), are still preferred by a substantial proportion of the population, have suffered from policy neglect, and are often viewed by the urban elite as a "poor man's crop" (Chinsman 1984).

The recent droughts in the Sahel and in eastern and southern Africa have increased the urgency with which national policymakers are considering drought-resistant crops. National agricultural research systems in many African countries have strengthened their programs to improve sorghum and pearl millet. A food crop, however, only becomes food when it is actually consumed. Efforts at increased food production must, therefore, be matched by corresponding research in crop use after harvest.

Need for dehulling technology

Most producers and consumers of sorghum and pearl millet face a daily task of dehulling and pulverizing the grains manually before being able to prepare the daily meal. Traditionally, sorghum and millet are dehulled:

- To remove the outer layers, which contain primarily fibre, the presence of which affects cooking quality and taste and texture of the product, and adds bulk to the daily meal; and
- To remove sources of bitter taste (polyphenols or tannins) that are often found in the outer hull or in the testa layer immediately under it.

The average rural homemaker and her children will save substantial energy and time if they have access to machinery that can provide a convenient and inexpensive dehulling and grinding service. Research in Botswana in the mid-1970s indicated that rural women, although preferring the taste of sorghum,

Table 1. Area, yield, and production of sorghum and millet by regions, 1981.

	Sorghum			Millet		
Region	Area harvested (× 1000 ha)	Yield (kg/ha)	Production (Gt)	Area harvested (× 1000 ha)	Yield (kg/ha)	Production (Gt)
World	48 384	1 493	72 228	43 065	676	29 127
Africa	15 925	751	11 960	16 605	620	10 294
North and Central America	7 780	3 749	29 171	–	–	–
South America	2 789	3 213	8 963	187	1 270	238
Asia	20 967	962	20 168	23 536	724	17 040

Source: Adapted from FAO (1984).

Table 2. Millet and sorghum production of selected African countries, 1981.

	Millet (Gt)	Sorghum (Gt)
West Africa		
Benin	7	57
Burkina Faso	443	659
Cameroon	351	nr[a]
Chad	496[b]	nr
Central African Republic	55	nr
Gambia	42	nr
Ghana	119	131
Mali	800[c]	nr
Mauritania	66	nr
Niger	1 314	322
Nigeria	3 180[b]	3 700[b]
Senegal	736	nr
Togo	107	nr
East and southern Africa		
Angola	50[b]	nr
Botswana	2	28
Burundi	39	243
Ethiopia	197	1 207
Kenya	130[c]	200[c]
Lesotho	0	48
Malawi	0	140[b]
Mozambique	5[c]	160[c]
Namibia	20[c]	2[c]
Rwanda	3[c]	175[c]
Somalia	nr	207
South Africa	15[c]	545
Sudan	573	3 345
Swaziland	2[b]	nr
Tanzania	150[c]	230[c]
Uganda	480	320
Zambia	30[c]	14
Zimbabwe	138	125

Source: Adapted from FAO (1984).
[a] nr = no value reported.
[b] Unofficial value.
[c] FAO estimate.

were prepared to purchase imported sifted maize meal because of its labour-saving convenience and off-the-shelf availability. Evidence is accumulating that the bottleneck of home processing of these drought-resistant crops is causing changes in planting and eating patterns, to the detriment of a sustainable agriculture in the dry areas. Farmers in the semi-arid areas are planting more maize despite an increased risk of crop failure because of erratic and low rainfall, and their families are consuming less sorghum and millet.

The absence of dehulling machinery also affects the buying patterns of the urban consumer. Usually engaged in an 8- to 12-hour job, she has little time for home

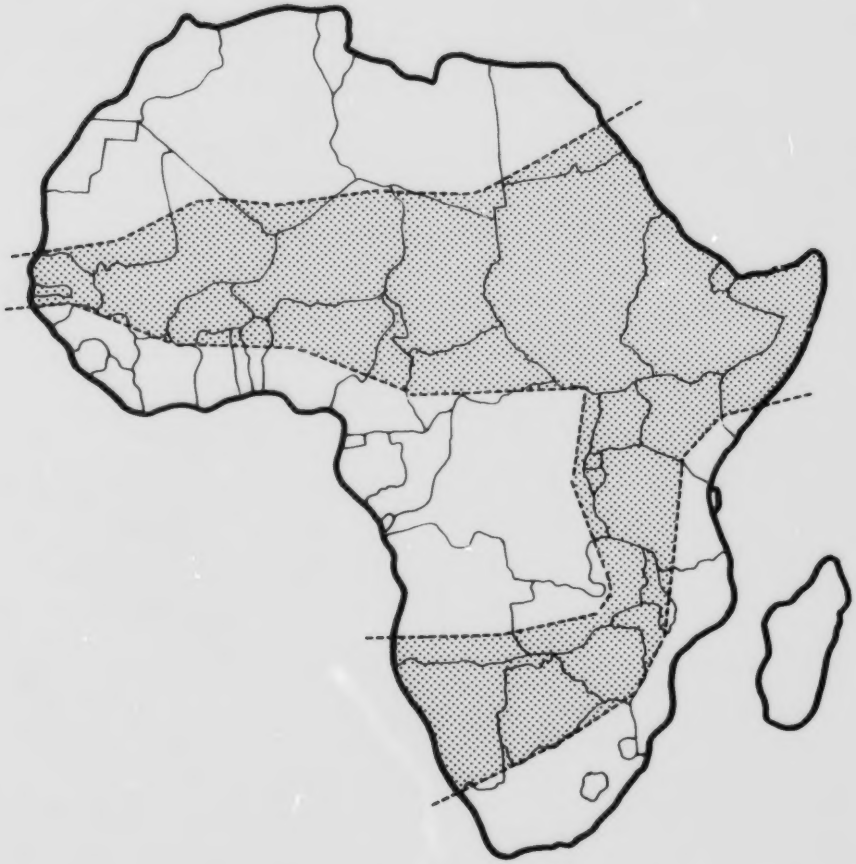

Fig. 1. Semi-arid areas of Africa suitable for growing sorghum and millet (shaded) (based on FAO 1978, figs 10.1 and 10.2).

processing of sorghum and millet. She will, therefore, buy the ready-to-cook maize meal or other convenience foods, regardless of her family's taste preferences.

Interventions by the International Development Research Centre

Since the inception of IDRC in 1970, the Centre has supported research by African and Canadian workers into both production and postproduction aspects of the neglected crops of the semi-arid tropics. Research support for sorghum and millet improvement in several African programs led to the following analysis: a successful outcome of the improvement research will lead to increased production of sorghum and millet. The increased volumes of these commodities will result in another set of problems. To solve these problems, the focus must be on postharvest research.

Beginning in 1972 in Nigeria, research support was provided to investigate the problems of processing and using these small grains, including cowpeas (Dovlo et al. 1976). Useful summaries of the efforts and interests of researchers in Africa in utilization and processing have been presented previously (Vogel and Graham 1979; Eastman 1980).

The intended beneficiaries of postproduction research support, spanning the work in Nigeria between 1972 and 1976 through to present activities in much of semi-arid Africa, have been the small-scale rural producer and consumer of sorghum and millet and of legumes such as cowpeas. The outcome of these research efforts has been a number of variants of a basic dehulling machine.

The hardware technology

The dehuller consists of a metal shaft on which a number of grinding stones or abrasive disks are evenly spaced about 2 cm apart. This rotor is enclosed by a semicircular sheet-metal barrel that is filled with grain. The abrasive disks, spinning at 1 500–2 000 rpm, rub against the freely moving mass of grain and abrade away the outer layers. Several design variants are described in Chapter 4.

All the variants are relatively small scale but they can be grouped into two size ranges, whose throughput capacities (for economic viability) match the demand levels of two population ranges. The smaller machines, the mini-dehullers, are suited to sparsely populated rural areas and are a response to the labour bottleneck of home processing experienced by each household within the mill's catchment radius. Making such machinery available to rural areas reduces the large costs associated with collecting raw materials and redistributing processed foods, so common to large-scale, centralized-processing industries. As well, the large, centralized-milling installations are imported at high capital cost and require further, scarce, foreign exchange for import of spare parts.

The larger variants, the PRL (Prairie Regional Laboratory) and RIIC (Rural Industries Innovation Centre) dehullers, are suitable for rural areas with higher population densities. These dehullers can also be deployed in parallel multiple production lines, capable of serving the larger volume demands that occur in towns and cities. The RIIC dehuller has been successfully used as part of a rural service mill on one end of the business spectrum and as a component of a fully commercial processing factory at the other end.

Overview of other chapters

The chapters of this book are intended to lead the reader through a logical sequence. The reader may, however, prefer a different sequencing, depending on interest and technical background. The policymaker may, for instance, wish to read Chapters 2 and 7 before returning to the more technical sections. A brief synopsis is, therefore, presented here for each of the chapters.

Traditional foods, user preferences, and grain quality (Chapter 2)

A feature common across Africa is that the rural housewife performs two tasks in converting cereal grain into edible food: she first follows several steps of primary processing and then several steps of food preparation. The specific sequences of each task vary from country to country and depend on the family's

established preference for one or other food end product. The wide range of dishes prepared from both sorghum and millet is reviewed, and then linked to particular grain characteristics required for satisfactory functional properties of the food in question. Interactions between grain quality and food quality have not been fully explored, but they have a bearing on the objectives of national breeding programs, as well as on determining whether dehullers are really needed in a particular food system.

Evolution of dry abrasive-disk dehullers and their applications in Africa (Chapter 3)

A selected history of the applied research undertaken in various African countries is presented. The objective of this nonexhaustive sequence is to emphasize several points: all of the work reported is related to the perceived need to promote the production and use of the drought-resistant cereals; much of the work was problem-driven, rather than technology-driven; a good understanding of the real problems perceived by the intended rural beneficiaries has led to significant modifications of the hardware technology; the research was conducted by scientists and engineers working closely with the intended beneficiary. The chapter emphasizes the activities of IDRC-supported researchers, and identifies significant and critical complementary work by others.

Dry abrasive dehuller designs (Chapter 4)

The basic operating principles of the dehuller — how and why it works — are introduced to give the reader a starting point for understanding the hardware technology. Next, sufficient technical information is supplied about each of the basic variant designs, and their usefulness to different client groups and rural realities is characterized. The chapter provides enough information to emphasize the important linkage between good characterization of the food problem and good engineering design. An important table presents the main reasons for the modifications that resulted in the different variants of the basic design.

Grain–machine interactions (Chapter 5)

The overall purpose of the book is to demonstrate that the replacement of manual dehulling by a machine is, in many cases, technically possible, socially desirable, and economically feasible. This chapter examines the action of removing the hull from a grain from two points of view: the important characteristics of grain structure that define its proneness, or resistance, to dehulling; and the nature of the abrasive material in the grinding wheel or disk. The chapter also defines relevant measures that combine to form a common system for reporting and comparing dehuller performance.

Small-scale milling systems (Chapter 6)

The chapter provides step-by-step guidance to the applied researcher for effectively using the hardware technology in a rural food system. Examples of several functioning small-scale grain-milling systems, which include dehullers, are provided. Factual information is given, the need for systematic experimentation is emphasized, and the spectrum of useful and needed data is clearly identified.

Moving from research to dissemination (Chapter 7)

The applied researcher must keep in mind the context of the food problem that prompted the initial hardware development. The distinction is made between technical research and research-for-development. The technical researcher's responsibility to ensure that research results are made useful to, and are used by, action-oriented agents is emphasized. The complete process from problem identification through to dissemination of a solution, adopted and used by the intended beneficiary, is formalized in several diagrams. The chapter ends by emphasizing the need for a comprehensive look at the food system, and for ensuring that technological research is directed to solving a prevailing food problem.

CHAPTER 2

TRADITIONAL FOODS, USER PREFERENCES, AND GRAIN QUALITY

Before we attempt to develop or introduce processing equipment, we must be aware of the various types of foods that are prepared from processed grains. A knowledge of how local populations process and appreciate certain grains is a prerequisite to having a piece of equipment successfully adopted. This chapter, therefore, discusses the following topics: traditional primary processing and its relation to acquired tastes; the diversity of food preparation and its dependence on grain types; and the fact that good quality grains and well-processed grains are local concepts. In general, the reader is constantly reminded that grain types, processed products, and prepared foods are location specific.

DIVERSITY OF FOOD PREPARATION

The final forms in which cereals or grain legumes are consumed in African countries vary, depending on traditional practices within and between countries. In achieving these end products, the rural housewife performs two main activities: primary processing and food preparation. Similarities and differences between traditionally prepared foods, using sorghum and millet, have been described in the literature (Vogel and Graham 1979; Boling and Eisener 1982; Da et al. 1982; Ejeta 1982; Gebrekidan and Gebrehiwot 1982; Mukuru et al. 1982; Obilana 1982; Scheuring et al. 1982; Sidibe et al. 1982). This section presents a comparison between several foods obtained from sorghum and millet to illustrate the importance of dehulling in the overall food-preparation process.

In general, sorghum and millet are traditionally dehulled by wetting with water to soften the pericarp (see Fig. 21), pounding (using a mortar and pestle) to remove this coating, and washing or winnowing to get rid of the bran. The dehulled cereal is transformed into coarse or fine flour (particle reduction) by pounding or using a hammer or stone mill to produce dry flour, or using a plate mill to provide a wet paste. Alternatively, a mechanical dehuller is used to remove the pericarp after which wet or dry grinding is done to give a wet paste or dry flour, respectively. Flour obtained from wet dehulled grains and the wet paste cannot be stored for more than a few hours without losing its quality, its organoleptic quality being different from flour obtained by dry dehulling.

The main products obtained from traditional and mechanical dehulling and grinding are shown in Fig. 2. However, some of the food-preparation steps are not shown to reduce the complexity of the diagram. The dehulled cereal is used whole, pounded or ground to give cracked or coarse grains, in a fine paste, or as a fine flour. Foods prepared after primary processing are in the form of boiled or steamed whole and cracked grains, stiff or thin porridges, and breads. Malted whole grain

can be transformed into nutritious flour. Undehulled grain is also processed into cracked grains or fermented into alcoholic drinks such as beer.

Various types of foods are prepared from sorghum and millet (Table 3). Most of the common foods are in the form of stiff porridge or thin porridge (fermented or unfermented), leavened and unleavened bread, and boiled dehulled whole grain. Although foods prepared from sorghum and millet in many countries may appear to be similar, methods of preparation do vary. For example, stiff porridges made from sorghum are eaten in Burkina Faso *(tô)*, Kenya *(ugali)*, and Nigeria *(tuwo)*. *Tô*, made from dehulled sorghum or millet flour, is usually acidic and unfermented. *Ugali*, prepared from dehulled millet and sorghum flour, is usually at neutral pH, but lemon juice may be added to the water used for cooking or the water may be

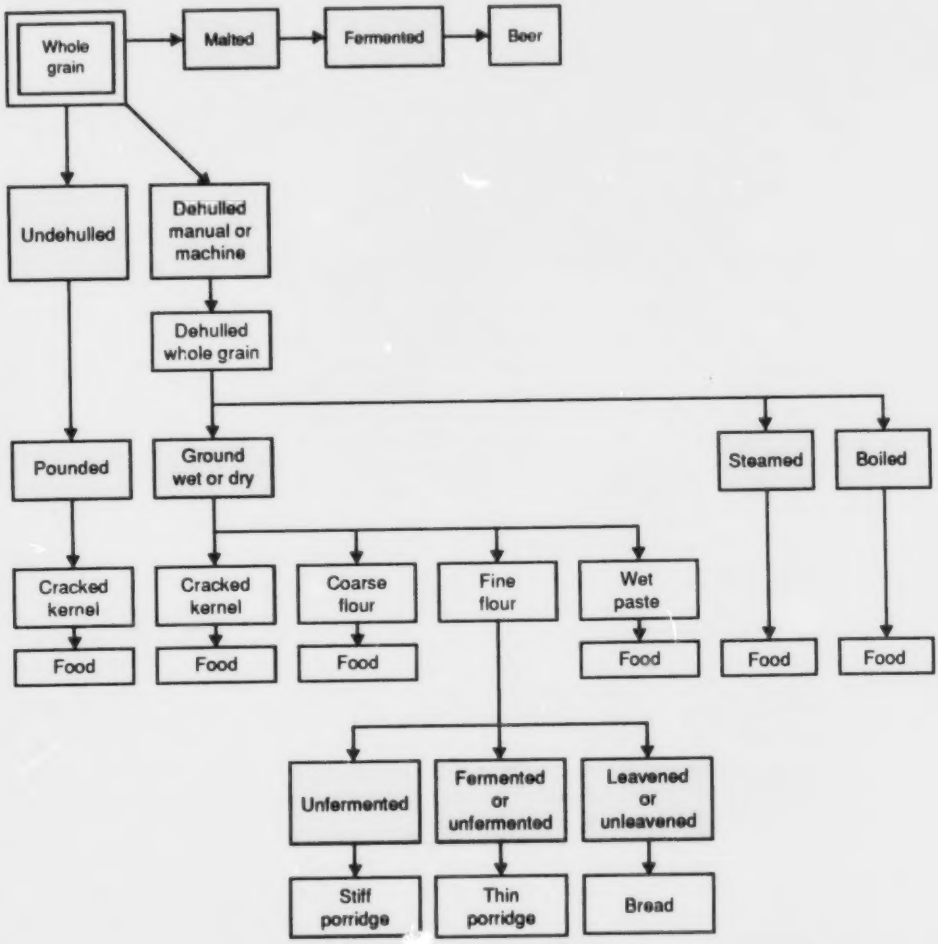

Fig. 2. Main products obtained from primary processing of sorghum and millet (shaded boxes denote processes).

replaced by milk and ghee. In Nigeria, *tuwo* is prepared from flour obtained by converting undehulled cracked sorghum grains into starch (by a wet process), drying, and then pounding. The foods shown in Table 3 are often eaten with other dishes. Thus, although cereals may predominate in the diets of many people, they are supplemented by legumes, vegetables, and oilseeds. The nutritional adequacy of the population's diet should, therefore, be judged on the basis of the diversity of their meals, not on the cereal alone (Futrell et al. 1985).

The effect that primary processing may have on the final food product is important. For example, a grain may pass along several possible paths from the undehulled to the milled state (Fig. 2), ending as a fine flour or wet paste. A stiff porridge prepared from the wet paste may have different colour, taste, texture, keeping quality, etc. compared to one made from dry flour. Thus, the use of mechanical dehulling and dry grinding may give a food product that is unacceptable to the user.

It is, therefore, important that primary processing using machines should give food products that are closely similar to those obtained using the traditional method. Studies on this topic, relevant to the preparation of some African foods using traditional and machine dehulling, have been reported (Boling and Eisener 1982; Da et al. 1982; Mukuru et al. 1982; Obilana 1982; Scheuring et al. 1982; Reichert et al. 1984b; Haidara et al. 1985). As an example, machine dehulling of sorghum is not common in Nigeria (Obilana 1982): traditional dehulling involving the wet process may cause fermentation of the grain, giving it a characteristic taste that dry machine dehulling will not replicate.

Sorghum, millet, other cereals, and legumes are traditionally dehulled and ground to prepare snack foods (Vogel and Graham 1979). Although these are not generally used as main meals by most of the people, they contribute to the breakfast or lunch diets of a significant number of the urban population because they are sold as street foods (EPOC 1985).

Another important use of sorghum and millet in some countries is in preparing local beverages (Novellie 1982). In general, the undehulled cereal is germinated, dried, pounded into flour, mixed with water, and allowed to ferment. Nonalcoholic beverages are obtained from lactobacillic fermentation of undehulled grains.

User preferences and grain quality

The preceding section showed the diverse types of food and methods of food preparation from sorghum and millet. Such differences indicate how the users have, perhaps after some selection, adapted to the quality of the available grain. They have, as a result, developed certain preferences that arise from the traditional methods of food preparation.

An important aspect of grain quality is the availability of nutrients and other substances in the grain before cooking. (A good summary of the composition of sorghum and millet is given in Hulse et al. (1980).) In practice, sorghum and millet have nutritional inhibitors whose level must be lowered before the grains are consumed. The presence of polyphenols gives a bitter taste to the grains (Bullard and Elias 1980) as well as reducing digestibility, thus lowering protein-efficiency level in humans (Hulse et al. 1980; Axtell 1985). This problem is worsened where breeders have introduced grains with high polyphenol levels to reduce bird attack

Table 3. Some common foods prepared from sorghum and millet in some African countries.

Local name	Processed product	Description	Country
dafa duka, ewa, dahuwa, oka baba	undehulled whole sorghum	boiled sorghum with beans, oil, pepper, onion	Nigeria
burabusko	undehulled whole millet	boiled millet with beans, oil, pepper, onion	Nigeria
kande	dehulled whole sorghum	boiled sorghum, salt and seasoning, and legumes	Tanzania
mtama mu bufuke	dehulled whole/cracked sorghum	boiled, mashed with boiled cowpeas and sweet potatoes, banana, or cassava	Kenya
pate	undehulled/dehulled cracked millet or sorghum	boiled with pepper, tomatoes, onion, salt, spinach, condiments	Nigeria
pearled *dura*	dehulled sorghum or millet	boiled or steamed grain	Sudan
uji	fermented or unfermented millet or sorghum flour	thin porridge with sugar, milk (or lemon juice)	Kenya, Tanzania
obungi bwa kalo	fermented millet flour	thin porridge (prepared in banana juice)	Uganda
obushera	coarse, malted sorghum flour	thin porridge with sugar, fruit juice, mashed banana, or milk	Uganda
edi	coarse, unfermented sorghum flour	thin porridge with sugar, fruit juice, mashed banana, or milk	Uganda
akamu, eko, ogi	fermented millet or sorghum flour	thin porridge with sugar, milk (or lemon juice)	Nigeria
koko	fermented millet or sorghum flour	thin porridge with flour balls	Nigeria
nasha	fermented sorghum flour	thin porridge with sugar	Sudan

nasha	unfermented or fermented millet flour	thin porridge with milk or honey	Sudan
ugali	sorghum or millet flour	stiff porridge (eaten with sauce)	Kenya, Tanzania, Uganda
tuwo	sorghum flour	stiff porridge (eaten with sauce)	Nigeria
saino	cracked sorghum	stiff porridge (eaten with sauce)	Nigeria
dalaki	sorghum starch	stiff porridge (eaten with sauce)	Nigeria
kafa, eku tutu	sorghum flour	stiff (slightly softer) porridge wrapped in leaves	Nigeria
kunu zaki	sorghum flour	stiff porridge (made from unfermented flour paste) mixed with sweet potato flour after cooking and left overnight	Nigeria
teso, atap, karo, kwon, kalo	sorghum or millet flour	stiff porridge (may be mixed with groundnut paste, sesame paste, banana, sugar, or boiled mangoes)	Uganda
aceda	sorghum or millet flour	stiff porridge	Sudan
waina	sorghum flour	unleavened thin bread (spiced and fried)	Nigeria
kisra	sorghum flour	leavened thin bread (baked)	Sudan
injera	sorghum flour	leavened thin bread (baked)	Ethiopia
masa	sorghum flour	leavened bread (fried)	Nigeria
mugabi	millet flour	leavened bread (from mixture of millet and wheat flour)	Uganda

Source: Based on Vogel and Graham (1979).

(Bullard and Elias 1980) — birds do not like the bitter taste of such grains. In such cases, foods prepared from the grains may not be acceptable to the consumer (Price and Butler 1980; Reichert et al. 1980).

To reduce the undesirable tastes due to the presence of polyphenols in sorghum and millet, the rural housewife dehulls the grains and often allows the processed product to ferment. These processing techniques — dehulling and fermentation — lower the polyphenol levels in the grains (Axtell 1985). In other cases, however, where grains with high polyphenol levels are unacceptable for food preparation, they are fermented into beer (Vogel and Graham 1979).

As a result of methods of food preparation, the optimum level of nutrients may not be available during consumption, and protein digestibility may be reduced (Axtell 1985; Rooney 1985). This is, however, partly corrected by introducing meats, vegetables, and grain legumes into meals based on sorghum or millet, and using certain food-preparation techniques that are known to increase the nutritional quality of the food (Axtell 1985).

The antinutritional effects of phytic acid in sorghum and millet should be mentioned. This acid forms insoluble compounds (phytates) with such mineral elements as calcium, iron, magnesium, sodium, and zinc, making them unavailable for use by humans. Phytic acid can also combine strongly with proteins at certain pH levels. However, because a substantial amount of this acid occurs in the grain (40–50% for sorghum), it can be significantly reduced by dehulling. The germ of sorghum, for example, has the highest percentage of phytic acid follow by the bran and the endosperm. Thus, traditionally dehulled grain may have a higher level of this acid compared to that produced by mechanical milling. (A useful summary of studies of phytic acid with respect to sorghum and millet has been given by Hulse (1980); see also Doherty et al. (1982).)

Goitre has been linked to the consumption of pearl millet (Osman 1981; Osman and Fatah 1981). Gaitan et al. (1986) have shown that pearl millet causes goitre when fed to rats under laboratory conditions and suggest that C-glycosylflavones (C-GF) may be the goitrogens. They also showed that the goitrogenic and antithyroid activity are present in bran fractions of millet with the highest concentrations of C-GF. However, because the C-GF concentration is markedly reduced by dehulling, as reported by Reichert (1979) (see Fig. 3, where the concentrations of C-GF are reduced from about 124 to 60 mg/100 g by abrading about 20% of the grain), the traditional practice of dehulling in several African countries is expected to reduce these negative effects of consuming millet.

Considering the need to reduce wastage in African countries, the keeping quality of various foods is important in food preparation. For example, users require that stiff porridges such as *tô* and *ugali* have good keeping quality. The literature suggests that keeping quality is related to the vitreousity of the endosperm; stiff porridges made from grains with vitreous endosperms keep well (Da et al. 1982; Mukuru et al. 1982). On the other hand, thin breads such as *injera* (used in Ethiopia) or *kisra* (from Sudan) are preferred when made from sorghum with a less vitreous endosperm (Da et al. 1982; Mukuru et al. 1982). (The response of sorghum eaters to traditional foods made from only the vitreous or only the floury endosperm components of sorghum has been reported by Hallgren (1985).) Typical dehulling characteristics of grain with different pericarp characteristics (using a Udy cyclone dehuller) are shown in Fig. 4. Both the Kamboinse Local and

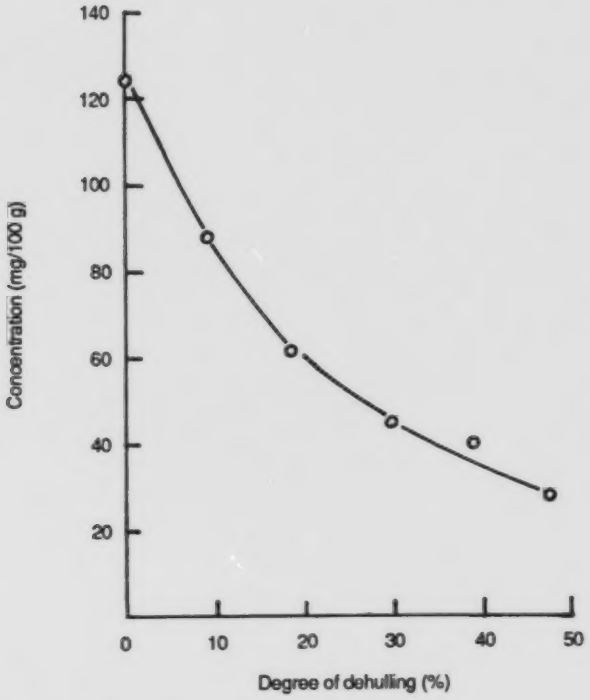

Fig. 3. Concentration of total C-glycosylflavones in dehulled millet grain (from Reichert 1979).

S29 sorghum (with a thick pericarp) have good dehulling properties and *tô* quality, whereas the TAM428 and 77CS2 (with a thin pericarp) have poor dehulling properties (Da et al. 1982). These studies suggest that the quality of the final food product depends on certain physical characteristics of the grain used and, considering the complex interactions between these two parameters, optimum processing of the grain will be expected to be location and user specific. The relationship between grain quality and food quality has been studied by Rooney and Murty (1982) and a good summary is presented by Rooney (1984).

Studies on the preference for a food by users show that this depends on factors that include colour, taste, degree of dehulling, texture, stickiness, and good keeping quality. Because these characteristics have been shown to depend on the variety of grain used, certain varieties are, therefore, preferred for certain foods (Da et al. 1982; Ejeta 1982; Mukuru et al. 1982; Scheuring et al. 1982). Foods that do not conform to the preferences of users are not accepted, resulting in the rejection of the particular variety of cereal from which it is prepared. However, methods for relating the quality of the food, which is a measure of user preference, to the variety of cereals are being developed and will be used increasingly by breeders in grain-improvement programs.

This discussion suggests that any attempt to replace traditional mortar and pestle dehulling by mechanical equipment should consider the whole food system rather

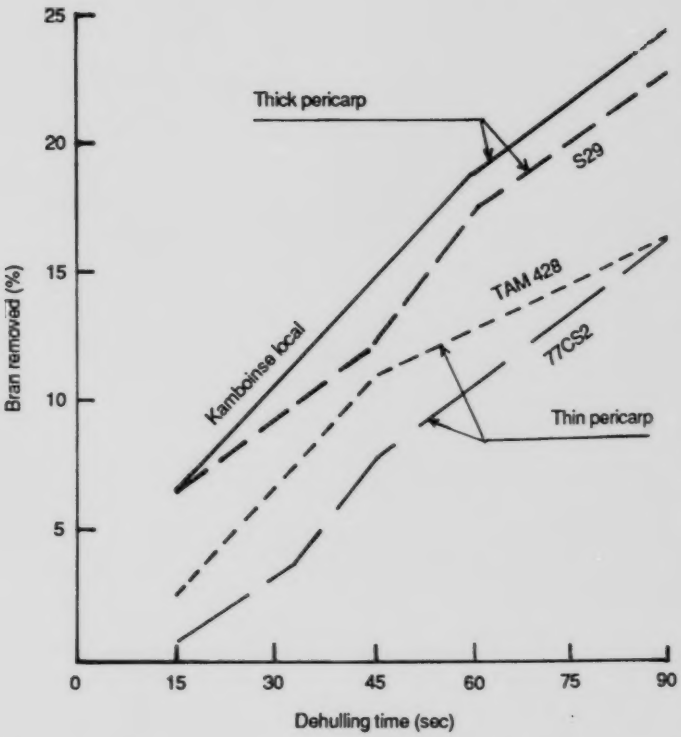

Fig. 4. Percentage of total bran removed from various sorghum varieties during dehulling using a Udy dehuller (adapted from Da et al. 1982).

than just the dehulled product. A dehuller should be operated so as to produce a dehulled grain that has a yield equal to the extraction rate (see Appendix A for definitions of these terms) because inadequate dehulling can cause unacceptable tastes to be present in the prepared food. In addition, an over-dehulled grain may not be acceptable because there is too much reduction in the available food. Thus, a dehuller destined for use in a locality should, initially, be used on local varieties to determine its appropriateness.

The points raised in this chapter illustrate the wide range of available information related to traditional foods, quality of grains and prepared foods, and primary processing of grains. A good understanding of the users' preferences for grains and food quality would increase the chances of their accepting the product obtained by a new processing technique, such as machine dehulling. Also, the varied eating habits and tastes of people suggest that solutions to a processing problem are best obtained on a case-by-case basis. For example, a program aimed at introducing a dehuller should consider the local grains used and the local population's preferences for the processed products and foods prepared from them.

CHAPTER 3

EVOLUTION OF DRY ABRASIVE-DISK DEHULLERS AND THEIR APPLICATIONS IN AFRICA

In this chapter, we have selected and described some of the grain-milling research projects supported by IDRC in Africa since 1972. All the projects relate to the perceived need to promote the production and use of small grains and grain legumes — particularly sorghum and millet — that constitute the staple food for significant rural populations. A major constraint to a successful promotion is seen to lie in the difficulty of dehulling the grains before grinding into flour.

The chapter follows a roughly chronological sequence, providing an overview of the evolution of dehuller designs and their application to a range of problems in different national contexts.

The applied research first emphasized the development and pilot testing of the larger of two sizes of dehullers, and is described in the first section. As different researchers encountered new field conditions, the need for a smaller dehuller was defined. The second section describes the evolution of several variants of a smaller dehuller. A body of experience is being established, and a network of researchers is emerging that is beginning to collaborate in a dynamically evolving process of problem solving. The final section deals briefly with significant attempts to introduce larger scale industrial or commercial dehulling and milling plants in several African countries. It also identifies the application of other design principles to dehulling of the common cereal grains.

For both sizes of dehuller, one can see the initial focus on the development of a suitable machine, succeeded by pilot tests in villages, and followed by wider scale introduction of the technology to additional target locations. This evolution of the research-for-development process is treated in more detail in Chapter 7.

LARGE DEHULLERS

Nigeria

Between 1972 and 1976, a project was conducted jointly by Nigeria's Federal Ministry of Agriculture and Natural Resources and the North-Eastern State's Ministry of Agriculture and Natural Resources and Ministry of Cooperatives and Community Development. As part of the project, a complete processing plant, consisting of a dehuller, hammer mill, and diesel engine to drive the equipment was established in Maiduguri. In 1974, the initial dehuller was replaced by a much more effective prototype, designed by the Prairie Regional Laboratory (PRL, now the Plant Biotechnology Institute, PBI) of the National Research Council of Canada

(NRCC). It was a modification of a barley thresher used by some Canadian processors. This PRL dehuller was the first in the evolution of the abrasive-disk dehullers (Reichert and Youngs 1976, 1977). The first phase of the Maiduguri project was devoted to the set-up, operation, and management of the pilot flour mill; the second to quality control, product development and testing, and establishing a bakery for preparing Nigerian-style bread containing sorghum flour (Steckle and Ewanyk 1974; Anon. 1975; IDRC 1976).

Thus, the project dealt with the technical and economic issues of establishing and operating a grain mill, gathered useful data on consumer preferences in grain utilization, applied this knowledge to the production choices made by the mill, and developed new products from sorghum, millet, and maize in the test kitchen adjoining the bakery. Complementary and collaborative work on analysis and development of foods from grain flours was conducted at the University of Saskatchewan in Canada.

The survey work verified that indigenous cereals and legumes were preferred by the consumer household, and that many households saw home processing as time consuming and a constraint to continued use of the preferred foods. The research objective of easing or even replacing home processing was thus validated. The technical research then demonstrated that the dehulling and grinding machinery were able to produce a range of "flours" (fine, coarse, semolinas, etc.) acceptable to the household and capable of being prepared into the preferred food end products.

The research appears to have had some effect on the rest of Nigeria. Toward the end of these phases, the National Grains Production Company (NGPC) in Kaduna built a plant with two dehullers of the PRL design, and applied them to dehulling maize. This latter activity appears to be continuing unabated.

Botswana

Independent research conducted between 1974 and 1975 by a Canadian agricultural economist identified two key issues (Hamilton 1975):

- Sorghum was the preferred staple food of rural dwellers and
- Rural food consumption patterns had changed significantly over the preceding years. Mainly because home dehulling and pulverizing by mortar and pestle were onerous and time consuming, women were purchasing more imported ready-to-cook sifted maize meal and rice.

Between 1975 and 1978, the Botswana Agricultural Marketing Board (BAMB) established a processing facility at its Pitsane depot in southern Botswana that was essentially a copy of the Maiduguri mill. The research quickly demonstrated that urban and rural households liked the flour from dehulled sorghum and were prepared to pay a 10–20% premium for this flour over the price of maize flour. By 1978, the facility was totally under local management, and processed and bagged 5–10 t of flour/day (BAMB 1982). The milling system was able to perform only on a continuous flow basis, and could not easily deal with small batches presented by individuals who sought a milling service for "their" sorghum.

Between 1978 and 1980, the Rural Industries Innovation Centre (RIIC) modified the PRL dehuller to make it more compatible with village needs. The addition of a trap door enabled small batches to be dehulled, and thus a customer

could obtain a milling service for "her" batch of sorghum. The new RIIC dehuller demonstrated the feasibility of service dehulling and grinding (RIIC 1980a). RIIC quickly moved from their first prototype, in response to inquiries from many potential investors, to the sale of a package containing dehuller, hammer mill, and engine (Eisener et al. 1979; RIIC 1980b). By 1986, about 25 small-scale mills were operating throughout the country, incorporating 35 dehullers. A mature small-scale milling industry has been established, covering the populous eastern portion of the country. Further research support, in 1983 and 1985, refined design aspects of the dehuller and strengthened the RIIC's manufacturing techniques.

In 1983, owners of the milling systems formed the Botswana Mill Owners' Association (BMOA) to strengthen this infant industry, as a lobby to influence government policy on pricing and supply of sorghum, and to make sorghum flour widely available throughout the country. The Association published a quarterly newsletter, *Milling News*.

The RIIC dehuller has established an enviable track record, providing a valuable example of a successfully conducted research-for-development sequence, including the dissemination of the hardware to new entrepreneurs. The "Botswana experience" has been well documented in the informal literature (Forrest and Yaciuk 1980; Narayan-Parker 1981, 1982; Hardie 1982; Fastenau 1983; PFP 1983; Schmidt 1983; Morei 1985; Gibbs 1986), but with very little in the formal (Eastman 1980; Whitby 1985; Schmidt 1988). Copies of the informal reports have been widely distributed to researchers in the Third World. The comprehensive experience cuts across a multiplicity of scientific disciplines, but has not been communicated effectively to academics in the applied sciences or social sciences, although it is familiar to development workers.

Ghana

Research began in 1976 at the Food Research Institute on using a PRL machine to dehull cowpeas (see also Reichert et al. 1979). The research indicated the dehuller's technical capability to dehull these common legumes, at least as cost effectively as existing labour-intensive practices. The project was a logical successor to the informative documentation of cowpea use (Dovlo et al. 1976). Although economic and political changes in the country prevented the work from being carried to an early conclusion, we understand that the work is being continued.

Senegal

In 1979, the National Agronomic Research Centre in Bambey (CNRA) began to use the PRL dehuller to dehull sorghum and millet (Mbengue 1985). The dehuller remains active and is now being used by a miller to supply the local market in the town of Bambey, although its capacity exceeds the demands of the Bambey market. A further factor that contributes to the dehuller's underuse is its inability to deal with small batches. Potential customers want their own grain returned to them. The more recent RIIC design would be more compatible with those demands.

This early work has led to fresh research, initiated in 1985 and conducted jointly by the equipment manufacturing company, the Société industrielle sahélienne de mécaniques, de matériels agricoles et de représentations (SISMAR), and CNRA, which is a component of the Institut sénégalais de recherches agricoles (ISRA).

This research is aimed at developing a medium-size dehuller that is expected to be more suitable to the level of population concentrations in Senegal and neighbouring countries.

Sudan

The Food Research Centre (FRC) in 1979 expressed interest in comparing the effectiveness of several dehullers: the PRL design (built by Nutana Machines Ltd, 2615 1st Avenue North, Saskatoon, SK, Canada S7K 6E9); the RIIC design (also manufactured by Nutana Machines in this case, because RIIC was filling Botswana demands first); the dehuller (confusingly also called the "FAO" dehuller) manufactured by the French Fondateur de l'atelier de l'ouest (distributed by Société Comia-Fao SA, 27, boulevard de Chateaubriant, 35500 Vitre, France); a later small version (Mini-PRL) developed by the PRL and found suitable for laboratory use (manufactured by Nutana Machines); and the Decomatic Sheller (manufactured by Bernhard Keller AG, Herostrasse 9, CH-8048 Zurich, Switzerland), part of an industrial sorghum-processing system supplied by the Food and Agriculture Organization (FAO) of the United Nations.

It was expected that a comparison of operating costs, energy consumption, ease of operation, different types of abrasive materials, and different design principles would provide important indicators for future research directions. FRC, after these essentially laboratory-based tests, intended to place one of the dehullers in a village situation. The Sudan, with the largest annual production of sorghum in eastern Africa, appeared to be the ideal place for such applied research. Although it proved impossible to complete the comparative evaluation, FRC continues to dehull sorghum and bakes composite wheat–sorghum bread products at a modest commercial level for the urban market.

Tanzania

In a first-phase project, spanning 1979 to 1982, equipment of the RIIC design (manufactured by Grain Process Enterprises Ltd, 39 Golden Gate Court, Scarborough, ON, Canada M1P 3A4) was placed in a rural location in the Morogoro region. The researchers of the Small Industries Development Organization (SIDO) intended to use this small factory (resembling the Botswana Agricultural Marketing Board's installation) to support the efforts of the National Milling Corporation to popularize sorghum flour in primarily urban markets. For several structural and economic reasons, the hoped-for cooperation between these two agencies did not materialize.

Much was learned in this project about the importance of adequately describing problems to define the scope of the applied research that was required. This particular research phase was probably too much technology-driven and insufficiently problem-driven. A second phase project, begun in 1982, is establishing four pilot milling systems of the RIIC type in very rural locations (SIDO 1982–86). In addition, the researchers are involved in training regional colleagues in SIDO to cope with a further 10 rural installations. Opinion remains divided whether effective demand for dehullers has been widely demonstrated. National investment decisions will depend on assessing effective demand and on the fate of policy decisions about current proposals for a strategy on drought-resistant cereals. The Department of Food Science and Technology of the Sokoine

University of Agriculture in Morogoro conducted research on sorghum use in parallel with the SIDO two-phase milling project (Bangu 1981–86).

Ethiopia

In 1980, toward the end of a three-phase sorghum-improvement project conducted by the University of Addis Ababa (the work is now being continued by the Institute of Agricultural Research, IAR), the Ethiopian Nutrition Institute (ENI) began work on sorghum use. Initially directed toward the urban consumer, the work has demonstrated the technical feasibility of producing the staple dish *injera* from *teff*–sorghum composite flour, and the nutritional adequacy of substituting dehulled local sorghum for imported wheat in the premixed weaning food *faffa* (ENI 1981–86; Svanberg 1983a, b; Zewdie 1984). The research has included some work on rural utilization of sorghum and is moving toward the pilot introduction of small-scale dehullers to rural areas. In 1982, the University's Institute of Development Research (IDR) started a pilot installation that included the RIIC dehuller as part of a complete rural mill. Progress of the research was severely affected by the drought-induced famines in that country, but useful knowledge was acquired (Shiferaw Gurmu 1986; Dejene Aredo 1987).

Kenya

In 1981, in Kenya, the FAO-sponsored *Sorghum and Millet Development Project* imported an RIIC design of dehuller, which has been in regular use since then at the Kenya Industrial Research and Development Institute (KIRDI). IDRC supported the training of a technician in operating skills at RIIC in Botswana. With financial support from the European Economic Community (EEC), and in collaboration with the UK-based Overseas Development Natural Resources Institute (ODNRI, formerly the Tropical Development and Research Institute, TDRI), KIRDI is investigating whether the introduction of whole dehulled sorghum into the urban market can create a sustained demand for surplus production of sorghum in the drier areas. A final report is pending.

Mini-dehullers

Researchers began to recognize the limitations posed by the size of the RIIC dehuller where the population is sparse. The economic viability of the dehuller (and of the necessary hardware that complements it) depends on the amount of grain processed daily. For instance, if the RIIC dehuller is to be part of an economically viable service mill, it should be located within easy reach (walking distance) of 8 000–10 000 persons. Many rural areas do not have such high population densities.

Researchers in the Gambia and Zimbabwe, therefore, considered the potential of a smaller dehuller that had been designed by the NRCC's PRL (Reichert et al. 1984b). Might this small design be made appropriate to the needs of sparsely scattered populations? Applied research, being conducted at rural milling sites in both countries, indicates that the two different approaches found to modifying the Mini-PRL dehuller and making it more rugged are indeed effective. The research, located where the users are, confirms that there is a home-processing problem, that customers accept the end product for their families, and that mill owners can obtain a steady and sufficient income from providing a milling service.

Table 4. Abrasive disk dehullers in Africa.

Country	Date	Dehuller type	Application
Nigeria	1972–76	2 PRL designs from Canada in Maiduguri	Sorghum, millet, cowpeas, maize
	1978	2 PRL designs from Canada	Maize, in factory in Kaduna
Senegal	1973	1 PRL design from Canada	Sorghum, millet, maize
	1985	2 PRL designs from Canada	Sorghum, millet, maize
	1987	10 Mini-SISMAR/ISRA I designs built in Senegal	Sorghum, millet, maize
		1 Mini-SISMAR/ISRA II design built in Senegal	Sorghum, millet, maize
Botswana	1976–78	2 PRL designs from Canada	Sorghum
	1978–85	Development of RIIC design, and manufacture of 36 for Botswana; and export of 50 to neighbouring countries	Sorghum
	1979	1 Mini-PRL from Canada	Sorghum, experimental
Gambia	1982	1 Mini-PRL from Canada	Millet, sorghum
	1985–86	Several modified Mini-CRS locally produced	Millet, sorghum
Ghana	1977	1 PRL design from Canada	Cowpeas
Tanzania	1979–82	2 RIIC type from Canada	Sorghum, some maize
		4 RIIC designs locally built	Sorghum
	1981	1 Mini-PRL from Canada	Sorghum utilization, at University
	1985	10 RIIC designs bought from Botswana	Sorghum
Burkina Faso	1980	1 Mini-PRL from Canada	Sorghum, cowpea, millet research

Ethiopia	1980	1 RIIC design from Canada	Sorghum improvement
	1981, 1983	2 Mini-PRL from Canada	1 rural, 1 laboratory
	1983	RIIC design from Canada	Sorghum, maize, barley in rural mill
	1984	1 RIIC design from Canada	Weaning food
	1985	1 Mini-PRL from Canada	Rural mill
		1 Mini-PRL locally manufactured	Rural location, barley, lentils
Sudan	1980	1 PRL design from Canada	Sorghum
	1980	1 RIIC design from Canada	
	1980	1 Mini-PRL from Canada	
Kenya	1981	1 RIIC design from Canada	Sorghum
	1983	5 locally built from RIIC drawings	Sorghum, maize, grain legumes
Egypt	1982	1 Mini-PRL from Canada	Faba beans, laboratory
Mali	1982	1 Mini-PRL from Canada	Sorghum research
		1 RIIC from Canada	Sorghum, millet
	1987	1 Mini-CRS from Gambia	Sorghum, millet
Zimbabwe	1984	1 RIIC from Botswana	Millet
		1 Mini-PRL from Canada	Sorghum, millet
	1985–86	7 Mini-ENDA locally built	Sorghum, millet, rural milling
Somalia	1985	1 Mini-PRL from Canada	Sorghum
Uganda	1985	Mini-PRL from Canada	Sorghum, millet improvement
	1986	1 RIIC from Canada	Maize, sorghum
Malawi	1986	2 RIIC from Botswana	Maize, sorghum
		1 Mini-ENDA from Zimbabwe	Maize, sorghum

The Gambia

The Catholic Relief Services (CRS) in the Gambia, after thorough testing of a Mini-PRL dehuller under village demand conditions (it dehulled 50 t of pearl millet over 12 months), found the Mini-PRL design to be insufficiently rugged (Nance and Colley 1985). The Mini-CRS modification is now being tested in new village locations, under conditions of communal ownership and management. An estimate of the countrywide requirement for the mini-dehuller justifies early collaboration with local workshops in manufacturing and modifying prototypes. Local manufacturing enterprises will become an integral part of the technology delivery system now being systematically developed, because the modifications are suited to local manufacturing expertise.

Zimbabwe

In Zimbabwe, a general awareness of a potential rural need for dehulling services was confirmed by a research process that included demonstrations of a Mini-PRL to rural communities. Information gathered from such village meetings and interviews with owners of rural hammer mills led to the strategy of placing dehullers, as pilot ventures, with such existing rural mills. Early modifications made by the research group ENDA–Zimbabwe (Environment Development Activities, a nongovernmental organization) created the Mini-ENDA dehuller. The principles of the modifications were tested for manufacturing feasibility by artisans in the informal metal-working sector in Harare, with helpful financial support from the US-based Appropriate Technology International (ATI).

The Mini-ENDA is, at present, being tested in five rural locations, under communal and individual ownership. Business management systems are being developed, customer-responses are being sought, and the technical performance of the mini-dehuller is being closely monitored. The researchers are paying attention to customer interviews, to documenting the amount of home-labour time saved, and to collecting information about local sorghum and millet cultivars (ENDA 1988). The growing Zimbabwean expertise with all aspects of the Mini-ENDA has culminated in funding by the Canadian International Development Agency (CIDA) of a wider scale diffusion of the disk dehullers (both mini- and RIIC-size) to rural and urban hammer-mill operators.

Senegal

Researchers from SISMAR and CNRA–ISRA developed and tested several prototypes under rigorous laboratory conditions, and a design has been chosen for village testing. The Mini-SISMAR/ISRA I has been manufactured and installed in 10 village locations and is being evaluated (Mbengue 1986). Results obtained have led to a cheaper and potentially better performing dehuller, the Mini-SISMAR/ISRA II, that will be manufactured by SISMAR. Ongoing work is also aimed at setting up production facilities for this dehuller to ensure lower unit cost and good quality control.

Summary

The description of the larger dehullers and the mini-dehullers provides an overview of the evolution and application of different designs that reflect both the

ingenuities of the researchers and different user contexts; however, the review has not been exhaustive. IDRC-supported research on pilot testing and introduction of dehullers is also being pursued in Burkina Faso, Malawi, Mali, Niger, and Zambia. Introduction of dehullers is being supported by ATI in Cameroon and Mali, using the Mini-CRS design. A more complete listing of the locations of abrasive-disk dehullers in Africa is given in Table 4.

An important shift has occurred over the years that cover the activities summarized here. Even during the development and refining of the dehuller variants, research emphasis has moved from the laboratory toward the domain of the intended beneficiary. There is increased understanding by researchers of rural realities and needs and of the role that carefully focused technical research can play in responding to those needs. Discussions about "rural fit," about food-systems concepts, and about utilization, marketing, and distribution are taking place with increasing frequency.

Simultaneous and complementary technical interventions

IDRC has not been the sole agency concerned with processing of sorghum and millet. Applied research has been conducted for the last 20 years by national investigators, international agencies, and private companies on other dehuller designs. Most of such efforts, however, have been directed at urban consumer targets. Results have been mixed: in some cases, the larger industrial-scale equipment has demonstrated its technical ability to produce flours that were acceptable to the consumers, whereas in others the products have not met consumer standards. In many cases, the equipment remains underused because insufficient surplus grain reaches the urban location from the farmers. Pricing policies, transport problems, and absence of grading standards for sorghum and millet contribute to this underuse.

The United Nations Development Programme (UNDP) and FAO established projects on *Research and Development of Millet and Sorghum Products for Industrial Applications* in Senegal (1970–74) and the Sudan (1975–80) (Kouthon 1984; Perten 1984). These projects also relate to the FAO's *Composite Flour* program (ECA 1985). European and other manufacturers of complete milling systems have made limited sales to some African countries of large-scale equipment intended for use on sorghum and millet. Brief performance specifications and design descriptions for the industrial-scale dehullers are presented by Reichert (1982).

As well, the Engleberg design of rice dehusker is being manufactured in West Africa (Abidjan Industries, BP 343, Abidjan, Côte d'Ivoire) and is applied as a wet-process dehuller to both pearl millet and sorghum. The same type of machine is occasionally used on maize as a wet or dry dehuller in eastern and southern Africa, and is manufactured by several companies in that region. The dehuller manufactured by the French Fondateur de l'atelier de l'ouest, and marketed by the former Senegalese parastatal SISCOMA (now SISMAR), had limited adoption in that country and appears to have fallen into disuse (Diouf and Berthe 1985).

CHAPTER 4
DRY ABRASIVE-DISK DEHULLER DESIGNS

All the abrasive-disk dehullers discussed in Chapter 3 are basically of the same design and operate on the same principle. The variations in the designs, discussed later, are intended to permit:

- *The quantities of grain available in different locations to be processed economically;*
- *A decrease in processing time;*
- *An improvement in quality of the dehulled product;*
- *More efficient dehulling; and*
- *Minimizing manufacturing and operating costs.*

The main design and operating features of this family of dehullers are initially described in this chapter, emphasizing not only their simplicity but also the need to understand the complex interaction between their various components and the grains to be dehulled. Specific designs of the larger dehullers developed in Canada (PRL and Nuhull) and Botswana (RIIC), the mini-dehullers from Canada (Mini-PRL), the Gambia (Mini-CRS), Zimbabwe (Mini-ENDA), and Senegal (Mini-SISMAR/ISRA I and II) are described, pointing out their salient physical and operating features. Finally, the importance of adopting a methodological approach in the design and development of abrasive-disk dehullers is discussed using real-life examples from present activities.

GENERAL DESIGN AND OPERATING PRINCIPLES

The basic design of the abrasive-disk dehuller (Fig. 5) consists of a trough-shaped barrel made of light-gauge mild sheet steel with a semicircular bottom, a rectangular top, and straight sides. Several abrasive disks (so named because of their wheel or disk shape), separated by spacers made of lightweight metal such as aluminum, are mounted on a horizontal shaft located through holes on opposite end plates of the barrel. The abrasive disks are secured in place so that they cannot slip on the shaft, which is positioned so that there is a constant clearance between the outer circumference of the disks and the semicircular portion of the barrel. Because the spacing between the disks is usually constant, the number of disks installed in a dehuller depends on the length of the barrel and the thickness of disks used.

In operation, the grain, whose quantity depends on the dimensions of the barrel, is loaded into the machine up to the shaft level and the abrasive disks are rotated about their horizontal axis by an electric motor or engine coupled to the shaft through a belt drive. The abrasive disks, partially buried in the grain, cause mixing

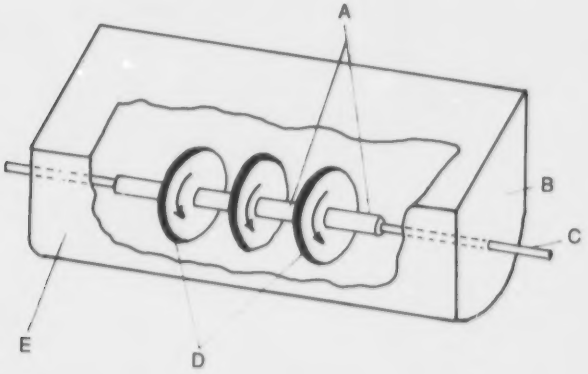

Fig. 5. Basic design concept of the abrasive-disk dehuller. A, spacers; B, end plate; C, shaft; D, abrasive disks; and E, barrel.

of the grains and removal of their pericarp as they come in contact with the disks' rough surface. In addition, the rubbing action between grains, during the dehulling process, may cause further pericarp removal. (See Chapter 5 for further explanation.)

The abraded material resulting from these machine–grain and grain–grain interactions forms fine dust particles. In some dehullers, the lighter bran is aspirated by a fan during dehulling, passed through a cyclone, and collected into sacks. These machines give whole dehulled grains, free of dust particles, which may be continuously discharged from the barrel or may be unloaded after processing. Dehullers without aspiration produce dehulled grains that must be separated from the bran by mechanical or hand winnowing or sieving. Incorporating aspiration in a dehuller and operating it in a batch or continuous mode depends on scale of operation and socioeconomic factors that will be discussed later.

The performance of abrasive-disk dehullers depends on 10 factors:

- Speed of rotation of the disks;
- Physical characteristics of the disks' surface such as roughness and hardness;
- Number and diameter of disks in the barrel, reflecting the total surface area available for dehulling;
- Spacing between disks;
- Clearance between the periphery of the disks and the barrel;
- Presence or absence of aspiration;
- Physical characteristics of the inner surface of the barrel;
- Feed rate of grains into the dehuller in the continuous mode, and the quantity of grain in the dehuller in the batch mode;

- Residence or retention time of the grain in the dehuller; and
- Physical characteristics of the grain.

The two basic types of abrasive disks that have been used in dehullers are grinding wheels and lightweight disks (commonly used by metal workers), which are obtainable in various sizes and with various surface characteristics.

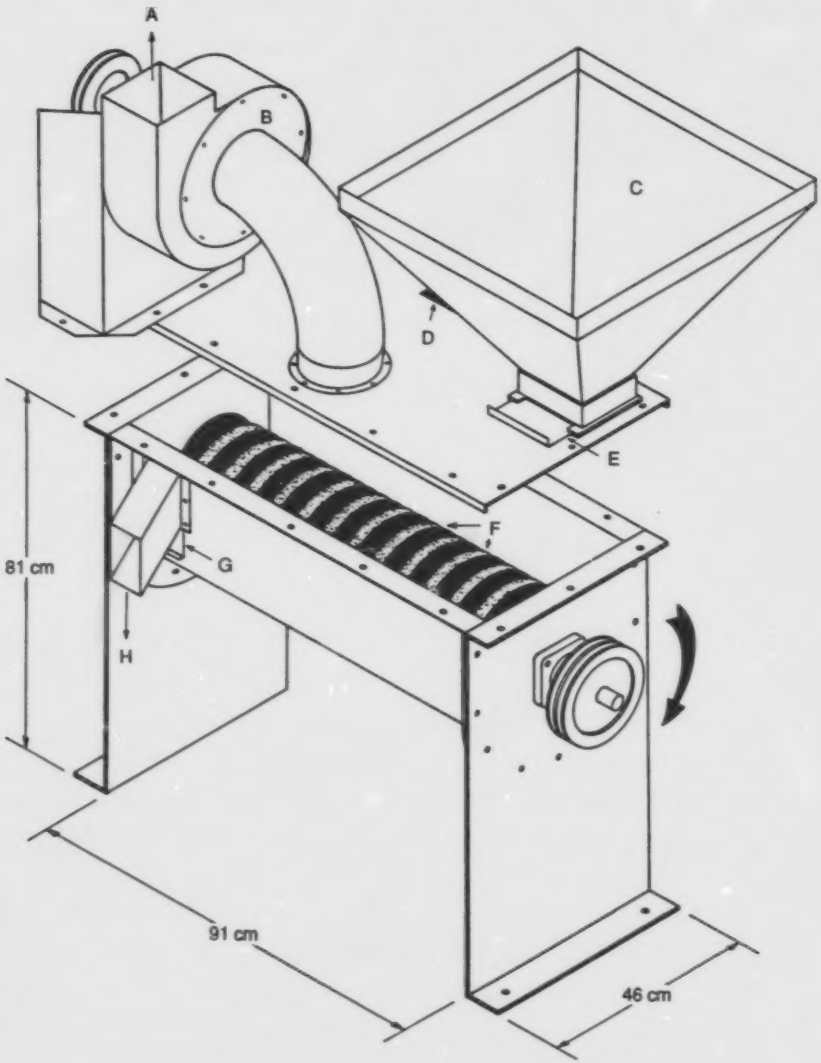

Fig. 6. Exploded view of PRL dehuller (from Eastman 1980). A, bran to cyclone; B, fan; C, grain hopper; D, air inlet; E, feed gate; F, resinoid disks; G, adjustable gate; and H, overflow outlet for dehulled grain.

Examples of grinding wheels are:

- 30.5-cm diameter, 3.2-cm thick carborundum stones made of extra coarse grit silicon carbide abrasives (85% of the total composition) with vitrified clay bonds and
- 25-cm diameter, 2.0-cm thick carborundum stones made of fine grit silicon carbide abrasives.

An example of lightweight disks is:

- 30.5-cm diameter, 0.64-cm thick resinoid disks made of medium grit aluminum oxide abrasive (67%), cured phenol formaldehyde resin bond (14%), and fluorspar (10.6%), which are reinforced with fibreglass (7%) to improve their strength.

Although the various types of abrasive disks and methods of characterizing the physical nature of their surfaces are discussed more fully in Chapter 5, we must emphasize that more knowledge is needed on the best choice for a given application. The lighter disks (such as the resinoid types) cause lower mechanical stresses on the rotating shaft whose diameter can thus be made smaller, reducing manufacturing costs. Also, a shaft containing an array of these lightweight disks can be rotated at substantially higher speeds than one carrying the heavier grinding wheels.

Descriptions of specific designs

Eight abrasive-disk dehullers that have, to date, influenced mechanical dehulling in various African countries are described in this section. Their physical differences are a result of local consumption patterns and dehulling habits, local economic and social conditions, available technical personnel and skills for both design and manufacture, design preferences of the engineers and researchers who developed the dehullers, and results of field testing. The larger dehullers (PRL, RIIC, and Nuhull) are more appropriate for industrial-scale grain processing, whereas the various mini-dehullers now in use are suitable for small-scale applications. (Names and addresses of the developers and manufacturers of the dehullers are listed in Appendix C.)

The PRL dehuller

The PRL dehuller (Fig. 6) is a modified version of the George Hill grain thresher (Reichert and Youngs 1976). The barrel is 86 cm long × 36 cm wide × 43 cm high and contains 13 carborundum grinding stones 30.5 cm diameter × 3.2 cm thick separated by aluminum spacers 1.5–3.0 cm thick on a 5.08-cm shaft. The clearance between the mounted abrasive disks and the inner walls of the barrel, which are covered with a 0.64-cm thick rubber lining, ranges from 1.5 to 3.0 cm. Barrel dimensions vary slightly for some of the dehullers that have been built and different disk sizes have been used.

During the operation of the dehuller, the disks are rotated between 900 and 1 300 rpm depending on the physical characteristics of the grain being processed. The grain is loaded into the hopper and the inlet feed gate is opened to allow the grain to enter the barrel. This initial charge is retained until the appropriate retention time is achieved. Continuous-flow dehulling is then achieved by matching

the settings of the inlet and outlet gates to ensure that the dehuller is always adequately full.

Dehulled grains flow out through an outlet located at the end of the barrel, farthest from the grain hopper. Bran, in the form of fine material, is separated from the dehulled grain by aspiration using a fan and cyclone system. The fan is driven by a belt and pulley system connected to the shaft on which the disks are mounted. The power to drive this shaft under load is about 8 hp (1 hp = 746 W). The direction of rotation of the shaft (Fig. 6) enables the fan to produce aspiration. Optimum airflow and bran removal is obtained by adjusting the air inlet and the adjustable outlet gates and the fan rotation rate.

Typical throughput of the PRL dehuller ranges from about 250 to 500 kg/hour at a speed of about 1 000 rpm using grinding stones, but this depends on the type and variety of grain being processed. Extraction rates ranging from 70 to 85% can be expected under these operating conditions. The minimum quantity of grain that can be dehulled is about 20 kg.

The RIIC dehuller

The RIIC machine, which was developed by RIIC in Botswana, has also been referred to in the literature as the PRL/RIIC dehuller (Dovlo et al. 1976; Eastman

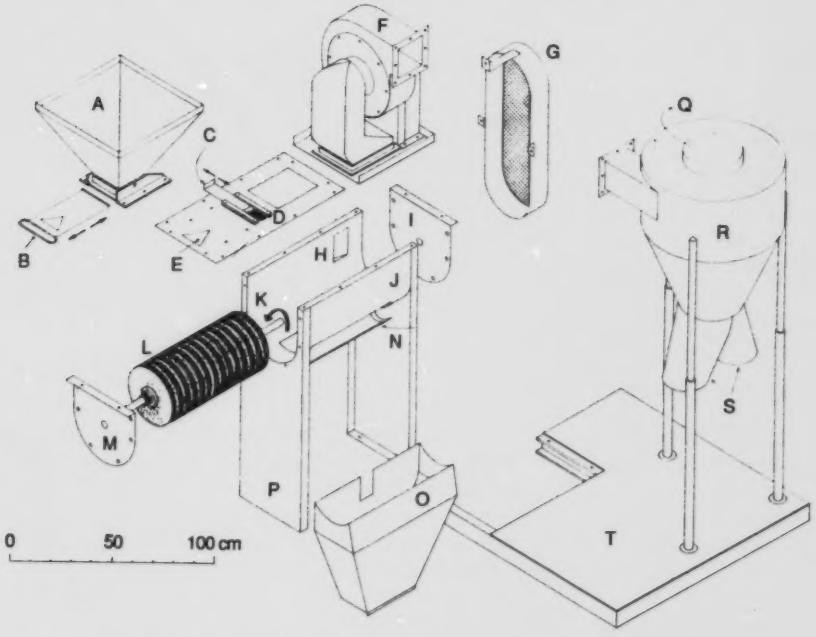

Fig. 7. Exploded view of the RIIC dehuller (courtesy of the Plant Biotechnology Institute, National Research Council, Canada). A, grain hopper; B, throughput control; C, air volume control; D, air inlet; E, grain inlet; F, fan; G, fan guard; H, outlet chute for continuous dehulling; I, end plate; J, dehuller barrel; K, direction of shaft rotation; L, grinding wheels; M, end plate; N, trap door for batch dehulling; O, outlet chute; P, stand; Q, air outlet; R, cyclone; S, fines chute; and T, base.

1980) and the RIIC/PRL dehuller. This machine has similar features to those of the PRL dehuller (Fig. 7) but the barrel is smaller (64 cm long × 30 cm wide × 33 cm high) — although these dimensions vary slightly among several models. A trap door at the bottom of the barrel permits the dehuller to be emptied after batch dehulling. Thirteen carborundum grinding stones, each 25.4 cm in diameter and 2 cm thick, are mounted on a 3.81-cm diameter shaft. The dehuller needs about 8 hp for full-load operation to rotate the disks at about 2 000 rpm during dehulling. Throughputs of up to 800 kg/hour can be obtained, depending on the grain type and required extraction rate, under continuous mode operation. In the batch mode, a minimum quantity of 5 kg of grain can be dehulled in about 3 minutes.

The Nuhull dehuller

A Canadian manufacturer, Nutana Machine Ltd, recently produced the Nuhull dehuller. It is a modified form of the RIIC dehuller, changes having been made to reduce cost and simplify manufacture. The overall features of this machine and

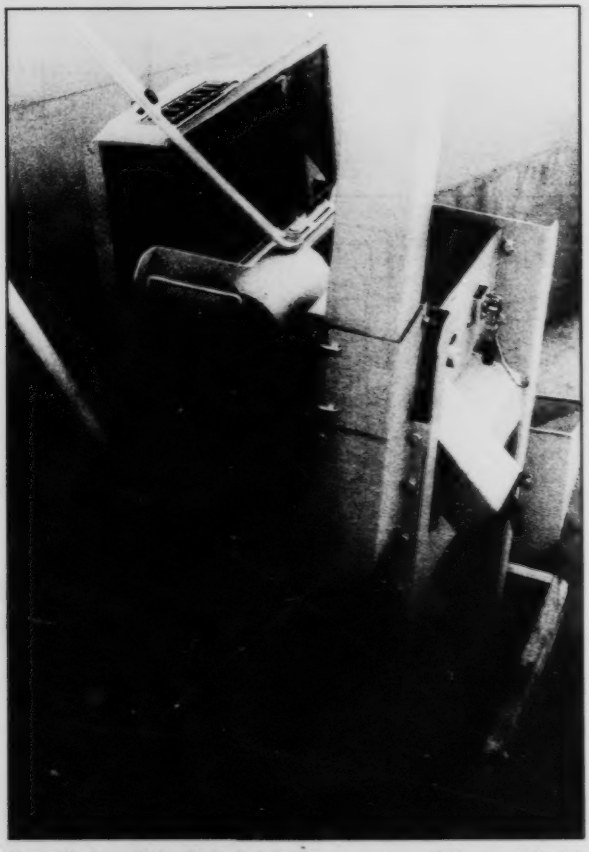

Fig. 8. Overall view of the Nuhull dehuller (courtesy of Nutana Machinery, Saskatoon, Canada).

reduce cost and simplify manufacture. The overall features of this machine and specific components are shown in Figs 8 and 9. In this model, the fan for aspirating the bran has been mounted directly on the end of the dehuller shaft and the airflow is controlled by a unique design. Carborundum grinding stones similar to those used in the RIIC dehuller are used in this machine. A 10-hp electric motor is needed to operate the dehuller at 1 500–2 000 rpm, giving throughputs between 200 and 500 kg/hour in the continuous mode. Batches of 5–15 kg can be dehulled.

The Mini-PRL dehuller

The Mini-PRL dehuller is substantially smaller than the PRL and the RIIC dehullers. (It has been called the Roll-over, Mini, PRL-Mini, and PRL Batch dehuller in the past.) It consists of a barrel 30 cm long × 30 cm wide × 32 cm deep, its shape being similar to the other dehullers discussed earlier. An overall view of the dehuller is shown in Fig. 10 powered by an electric motor.

The abrasive disks are mounted on a 2.54-cm shaft — resinoid disks 25.4 cm diameter × 0.32 cm thick or grinding wheels 25.4 cm diameter × 2.0 cm thick have been used. Where the resinoid disks are used, eight of them are separated by 2.5 cm spacers, the two end disks are inclined at 8° from the vertical to facilitate mixing of the grains (see Fig. 11). In some Mini-PRL dehullers, the six inner resinoid disks are replaced by four carborundum grinding wheels.

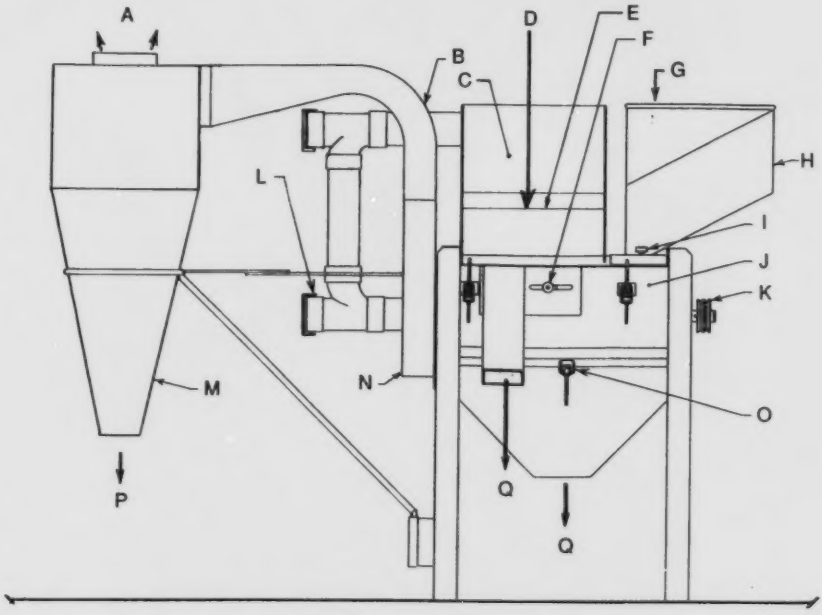

Fig. 9. Components of the Nuhull dehuller (courtesy of Nutana Machinery, Saskatoon, Canada). A, exhaust air; B, fan/cyclone duct; C, air suction channel; D, air inlet; E, dehuller body air inlet; F, grain outlet control; G, grain loading; H, grain hopper; I, grain inlet flow control; J, dehuller body; K, drive pulley; L, airspeed control; M, cyclone; N, fan; O, bottom grain dump control; P, bran outlet; and Q, dehulled grain outlet.

Power needed to operate the dehuller is about 3 hp generated by an electric motor or 5 hp generated by a diesel or gasoline engine. When an engine is used, because the dehuller's disks must be stopped periodically to load and unload the grain, a "ball-lock" clutch replaces the drive pulley. The general arrangement of the main components of the assembled Mini-PRL dehuller compatible for engine operation is shown in Fig. 11. It is important to note that the direction of rotation of the dehuller is such that the locknut preventing the disks from slipping on the shaft is not undone during operation. Thus, for a right-hand nut, the direction of rotation is as shown in Fig. 11.

Because the dehuller operates in a batch mode, it is necessary to load and unload the grain during use. Loading is effected by opening the hinged top cover (Fig. 10A) and pouring in the grain. After dehulling, the cover is opened, the pin is pulled (Fig. 11) allowing the machine to swing freely about the shaft axis, and the grain is dumped into the chute (Fig. 10B). The maximum recommended capacity is 7 kg of grain.

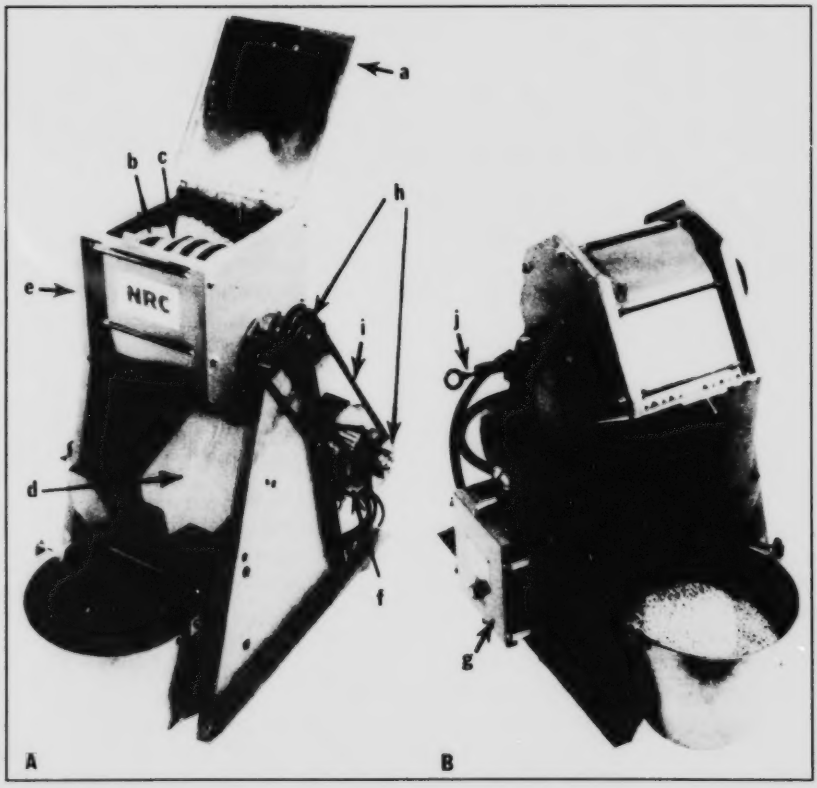

Fig. 10. The Mini-PRL dehuller in upright (A) and dumping (B) positions (courtesy of the Plant Biotechnology Institute, Saskatoon, Canada). A, lid; B, disk; C, grain; D, chute; E, dehuller barrel; F, electric motor; G, control panel; H, pulleys; I, belt drive; and J, spring-loaded release pin.

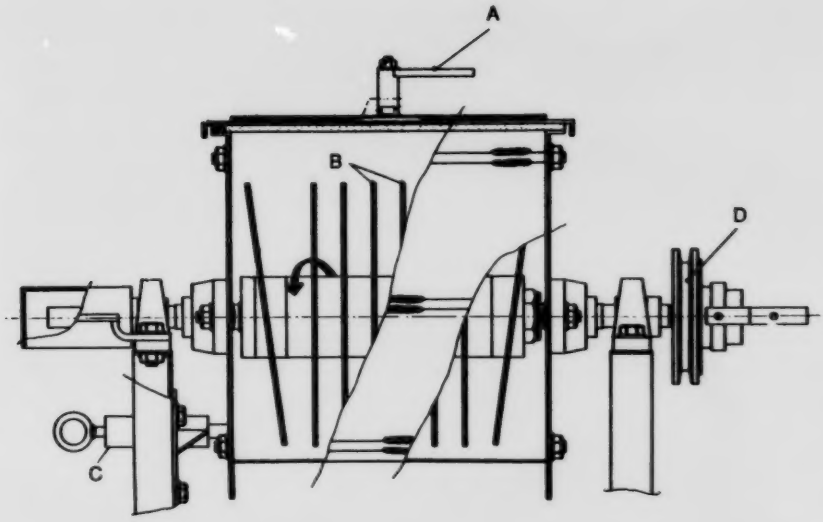

Fig. 11. Vertical section of the Mini-PRL dehuller with a clutch (courtesy of the Plant Biotechnology Institute, Saskatoon, Canada). A, latch; B, disks; C, spring-loaded release pin; and D, clutch.

In operation, the abrasive disks are rotated at 1 500–2 000 rpm depending on the grains being dehulled and the number and types of disks used. Dehulling times for sorghum and millet range from 2 to 5 minutes. An indication of the performance of the Mini-PRL dehuller and the range of grains it can process are shown in Table 5.

The Mini-CRS dehuller

Based on over 3 years of continuous village use of a Mini-PRL dehuller in the Gambia, changes have been made to overcome machine wear due to vibration, to simplify its manufacture and use, to minimize maintenance and repairs, and to encourage manufacture by local artisans (Nance and Colley 1985).

The main features of this machine (the Mini-CRS dehuller) are shown in Fig. 12. The dehuller is made in machine shops by local artisans using available tools and its fabrication does not depend on close tolerances or specialized manufacturing techniques. The barrel has the same dimensions as the Mini-PRL dehuller but it is made more robust to withstand fatigue caused by vibration. The disk and shaft assembly is similar to that of the Mini-PRL, but the locknut is replaced by a more convenient locking mechanism (Fig. 13). The end disks are angled at 6° to minimize breakage during operation.

A simple lever, using a used engine valve spring, has been incorporated to replace the spring-loaded pin used on the Mini-PRL dehuller for dumping the dehulled grain. In addition, the mechanism for closing the dehuller lid on the Mini-PRL has been changed to provide a tighter seal that reduces the escape of dust from the dehuller during operation. The imported "ball-lock" clutch on the Mini-PRL has been replaced by a simple clutch, made of mild sheet plates, needing no sophisticated manufacturing methods or skills (Fig. 14).

Table 5. Performance of the Mini-PRL dehuller in processing various grains.

Grain	Dehulling time (minutes)	Yield (%)
Millet	1–3	90–95
Sorghum	2–6	73–89
Brown rice	1–3	84–92
Wheat	3–6	77–93
Soybean	2	90
Faba bean	1	83
Lentil	1	85
Kidney bean	2	84
Mung bean	3	74
Black eyed cowpea	2	80
Brown cowpea	3	74

Source: Adapted from York (1981).

The Mini-ENDA dehuller

One of the main features of the Mini-ENDA dehuller is its longer barrel compared with the Mini-PRL machine. The barrel has the same shape as the other machines, but is 50 cm long × 30 cm wide × 30 cm deep and has a capacity of about 10 kg (Fig. 15).

The top lid of the Mini-ENDA dehuller can be removed for maintenance. Grain is loaded into the barrel using a hopper. Ten carborundum grinding wheels (25 cm diameter × 2.5 cm thick) are mounted on a 3.3-cm shaft and separated by 2.5-cm spacers. The abrasive-disk assembly is mounted on bearings as shown in Fig. 16. The pillow-block bearings used by both the Mini-PRL and Mini-CRS dehullers have been eliminated from the Mini-ENDA design because this dehuller does not need to be rotated about the shaft axis to empty it. Instead, the dehulled grain passes out through a trap door underneath the barrel, operated by a lever mechanism, and then flows into a chute (Fig. 15). Under village conditions, the Mini-ENDA can dehull 400–600 kg/day at a shaft speed of 1 500–2 000 rpm using a 3-hp electric motor.

The Mini-SISMAR/ISRA dehuller

Based on the design and operation of the Mini-PRL dehuller, SISMAR in collaboration with CNRA designed and built two prototypes, the Mini-SISMAR/ISRA I and II dehullers, having the same capacity as the Mini-PRL. The Mini-SISMAR/ISRA I dehuller (Figs 17 and 18) has a dehulling chamber that is similar to the Mini-CRS machine and must be tilted to empty the dehulled grain. One of the main differences between it and the Mini-CRS or Mini-PRL dehuller is the incorporation of a grain cleaner that uses a screen and rotating brushes to separate the grain from the bran. The mixture of the dehulled grain and bran is dumped into a receptacle that progressively feeds the material into the winnower where the bran is separated from the whole grains through a sieve by aspiration. The cleaned grain is collected through an outlet and the bran bagged after passing through a cyclone. Dehulling and winnowing of separate batches of grain can take place simultaneously.

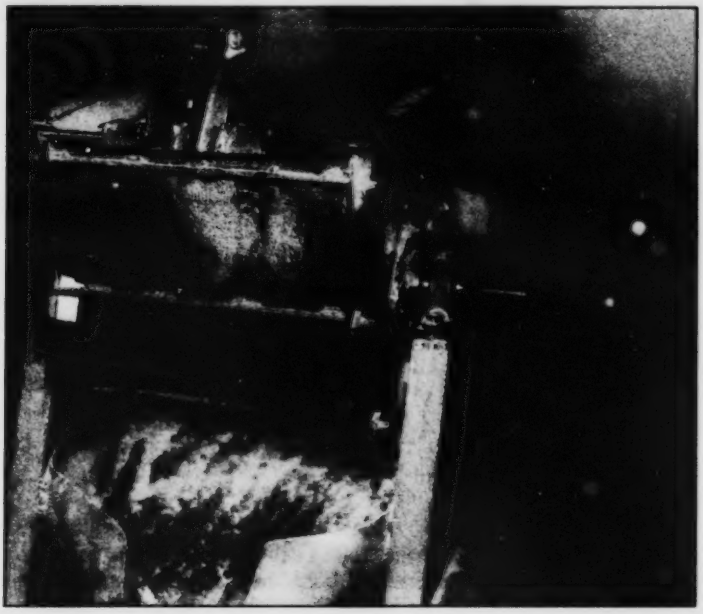

Fig. 12. Overall view of the Mini-CRS dehuller.

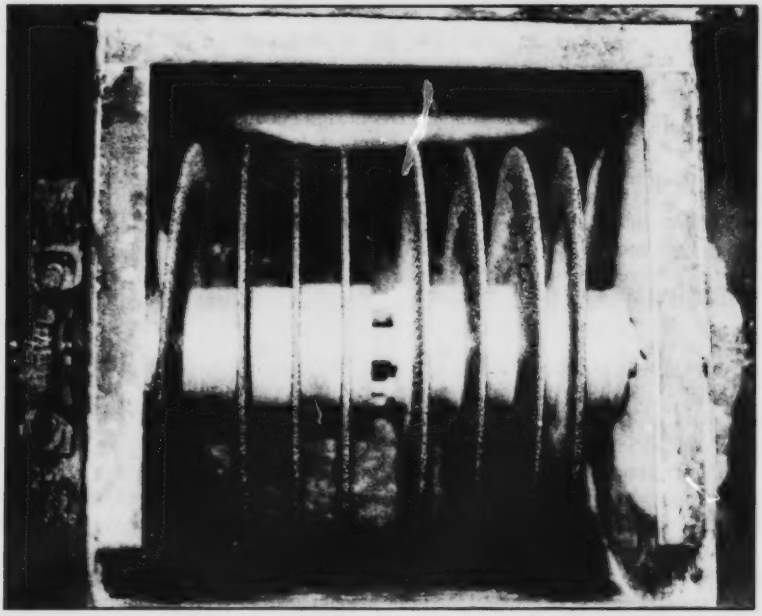

Fig. 13. Method used to lock the disks in the Mini-CRS dehuller.

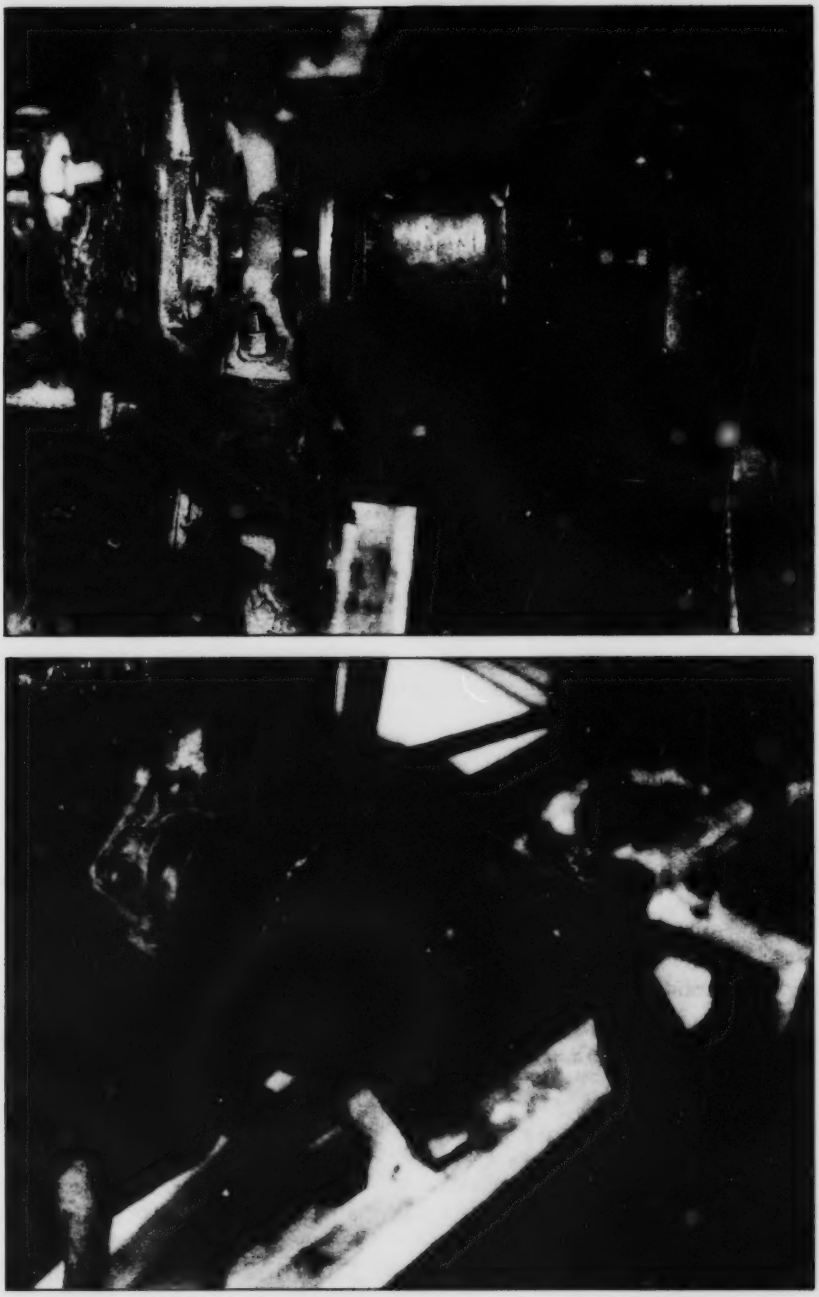

Fig. 14. The Mini-CRS dehuller showing the locally made clutch (top, engaged; bottom, disengaged).

Fig. 15. General features of two sizes of the Mini-ENDA dehuller for batch operation.

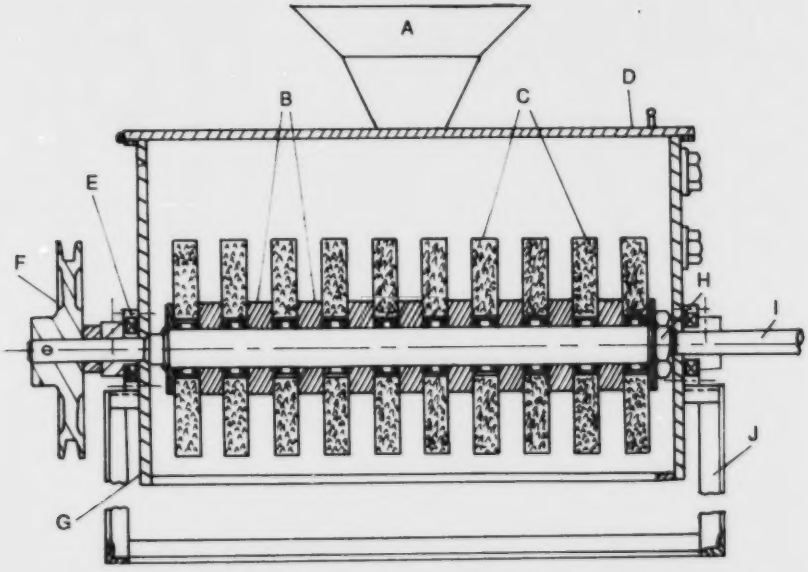

Fig. 16. Longitudinal vertical section through shaft of the Mini-ENDA dehuller (courtesy of ENDA-Zimbabwe). A, hopper; B, spacers; C, disks; D, cover; E, bearing; F, pulley; G, end plate; H, locknut; I, shaft; and J, stand.

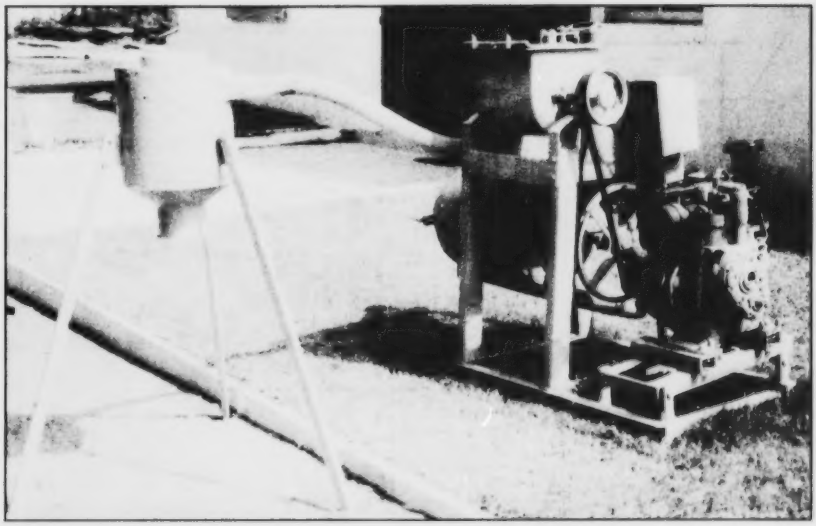

Fig. 17. General features of the Mini-SISMAR/ISRA I dehuller (courtesy of SISMAR, Senegal).

Ten lightweight resinoid disks are used in the dehuller but unlike the arrangement in the Mini-CRS dehuller, the end disks are at right angles to the rotating shaft (Fig. 18). Power is provided by a 6.5-hp diesel engine with a clutch or a 3-hp electric motor.

Certain basic criteria must be met before a dehuller fulfills a given dehulling need. Based on field tests results of the Mini-SISMAR/ISRA I dehuller, a second prototype, the Mini-SISMAR/ISRA II, has been developed to account for the villagers' need to economically dehull less than 4 kg of grain — the quantity usually dehulled in Senegalese villages (see Chapter 6) and to lower its cost. The Mini-SISMAR/ISRA II dehuller (see Figs 19 and 20) uses 8 resinoid disks rather than 10 but the winnower and cyclone are effectively the same as those in prototype I (Fig. 19). The barrel is divided into two compartments (Fig. 20) that are supplied with grain from two hoppers at the top of the dehuller. This allows two different batches of about 4 kg each to be dehulled simultaneously, while a third batch is being winnowed.

Instead of tilting the barrel to empty it after dehulling, the chamber is fixed (eliminating two sets of bearings) and two trap doors underneath the barrel are used to empty the mixture of bran and dehulled grain into the hopper feeding the winnower. The Mini-SISMAR/ISRA II is powered by a 6.5-hp diesel engine without a clutch. Because the barrel is no longer tilted to empty it, it is not necessary to isolate the engine drive from the dehuller's shaft. This arrangement substantially reduces the cost of prototype II from that of prototype I.

STAGES OF DEVELOPMENT AND USE OF DEHULLERS

In this section, we briefly discuss the extent to which the specific designs have been used and their possible future application.

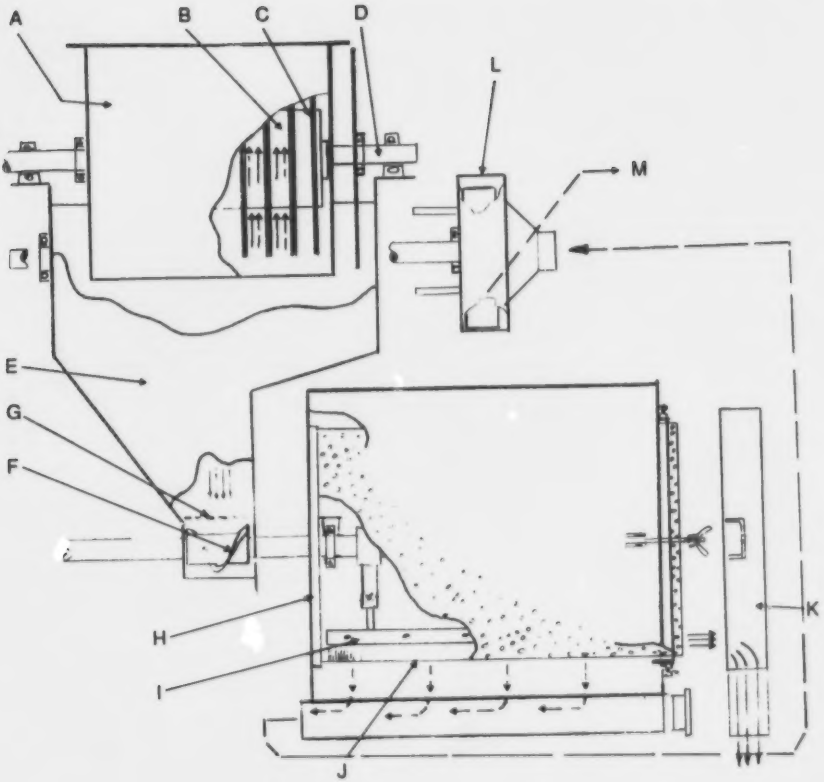

Fig. 18. Schematic of the Mini-SISMAR/ISRA I dehuller (courtesy of SISMAR, Senegal). A, dehuller; B, spacer; C, disk; D, shaft; E, feed box; F, Archimedean screw feed; G, grill; H, separator; I, brush; J, sieve; K, cover; L, aspirator fan; and M, to cyclone. Solid arrows, movement of dehulled grain; and broken arrows, bran.

The PRL dehuller is no longer being manufactured as it has been superseded by the RIIC and the Nuhull machines, which are more versatile. The RIIC dehuller is well entrenched in the sorghum-processing system in southern Africa where large volumes of the grain must be dehulled. It will continue to find a place in other African countries, especially in large villages or towns where commercial milling exists. Changes will undoubtedly continue to be made to reduce cost and improve performance, as exemplified by the Nuhull dehuller.

The Mini-CRS dehuller has been developed to a stage where it is ready for wide-scale adoption in the Gambia. It is being manufactured by a local artisan for use within and outside the country and several are in operation in the Gambia (as discussed in Chapter 6). Efforts are now being made to develop a self-sustaining manufacturing and service industry to satisfy the local market. Because there are similarities between many West African countries, the dehuller is being field tested

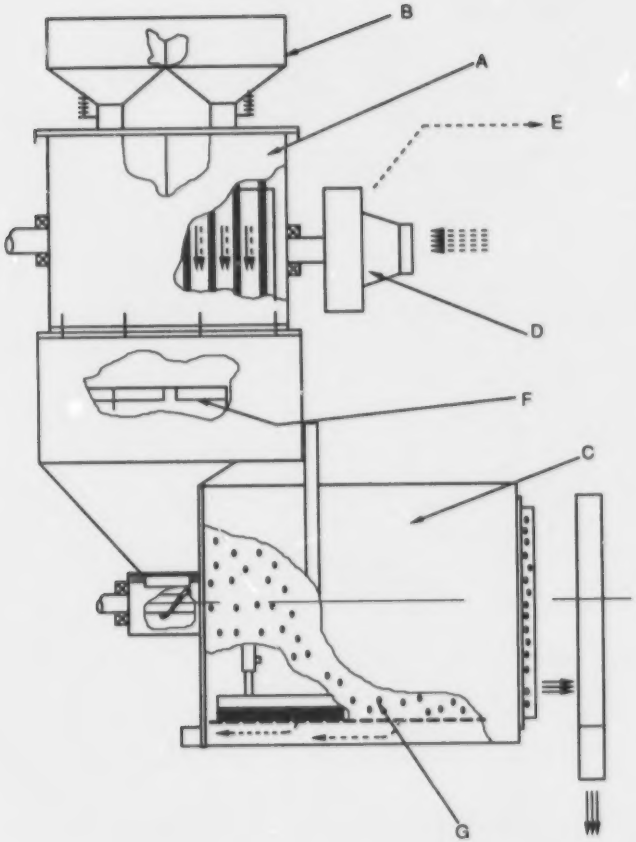

Fig. 19. Schematic showing specific features of the Mini-SISMAR/ISRA II dehuller (courtesy of SISMAR, Senegal). A, dehuller; B, feed box; C, separator; D, aspirator fan; E, to cyclone; F, two trap doors; and G, sieve. Solid arrows, movement of dehulled grain; and broken arrows, bran.

in Cameroon, Mali, and Niger with a view to manufacturing locally in these countries.

SISMAR in Senegal is in the process of manufacturing the Mini-SISMAR/ISRA dehullers. Several of the Mini-SISMAR/ISRA I machines are undergoing field testing (see Chapter 6). Results are being accumulated on their performance under real-life conditions. The Mini-SISMAR/ISRA II dehuller is being promoted by SISMAR and manufacture and commercialization has started. It is expected that this dehuller will be sold within Senegal and exported to other countries where dehulling needs are similar.

Activities are underway to promote the use of the Mini-ENDA dehuller in Zimbabwe. This project involves the manufacture and use of 40 dehullers with funding from CIDA.

Fig. 20. General features of the Mini-SISMAR/ISRA II dehuller.

We can conclude from this that these dehullers are past the development stage and are being manufactured and used to varying degrees in various countries. Further efforts are needed to maintain viable manufacturing structures and create the necessary socioeconomic climate for their acquisition and use.

METHODOLOGY FOR ACHIEVING APPROPRIATE DESIGNS

It would have been ideal to develop a single model of the abrasive-disk dehuller for use in all the African countries. This, unfortunately, was not possible because of the different agricultural, economic, political, and technological situations; availability of personnel; and traditional norms, which determined the choice of a dehuller. The approach used in developing the various designs was to acquire a technology and adapt it to a given dehulling need, accounting for the differences that may exist between countries. For example, the RIIC dehuller, which is well adapted to the needs of Botswana, is inappropriate for rural applications in Senegal. Also, because the quantities of grain that rural women dehull in the Gambia are relatively smaller, the Mini-ENDA machine will not give satisfactorily dehulled products nor will its performance be economically viable in the Gambia. In this

section, we discuss the importance of using a methodical approach to obtain an appropriate dehuller design.

It is immediately obvious that all the developments leading to the different dehullers used existing designs as a starting point. Changes were based on the quantities of grains that had to be dehulled, batch versus continuous dehulling, local manufacturing capabilities, availability of construction materials, the price of a dehuller, local design expertise, and the personal bias of the designer.

The interrelationship between laboratory and field work in achieving user acceptability of the dehullers is also shown in Table 6. Although their design generally involved substantial laboratory work, prototypes were taken out to the intended user in the early development stages to obtain feedback for further development. In all cases, the various designs have proved to be suitable for use within the countries where they were developed.

Experience gained from the activities outlined in Table 6 suggests that a general approach for developing appropriate dehuller designs can be formulated. Thirteen major questions must be answered within such an approach.

- Is dehulling perceived to be a problem by women and is it a constraint to food use and a better standard of living?
- Are there reliable statistics on production and use to justify a dehulling activity and are there enough grains to be dehulled in the area where the dehuller will be installed to make it economically viable?
- Is there also a grinder in existence?
- Have the grain-processing needs of the intended beneficiaries been assessed through surveys?
- What is the ability of the beneficiaries to pay for the purchase and upkeep of the dehuller?
- How much will the dehuller be used, how many users are there, and what are their dehulling habits?
- Is there a dehuller design in existence that can be used?
- If a dehuller exists, must its design be changed on the basis of knowledge of local conditions and the target grains?
- What is the expertise of research or development groups to carry out design changes? Can a collaborator with appropriate experience be found?
- What is the local capacity to build the machine? Is the existing technological infrastructure adequate?
- Can the capital and operating cost of the dehuller be minimized in the new design?
- Can complicated manufacturing procedures and those needing sophisticated equipment be eliminated from the design?
- Can all the component parts of the dehuller be manufactured locally?

In addition, five further points must be considered within this approach.

Table 6. Comparison of activities surrounding the design of the abrasive-disk dehullers.

Dehuller	Aim	Original design	Work done	Result
PRL	Develop dehuller for cereals and grain legumes	Hill thresher	Redesigned Hill thresher and tested on grains to assess performance Tests done in Africa under lab and field conditions Developed knowledge of dehulling needs in Africa	Dehuller used in several countries Dehuller appropriate for large-scale processing Interest developed in machine dehulling Dehuller inappropriate for some village use as too large and it did not dehull in batches Dehuller suited for wide range of grains
RIIC	Develop appropriate dehuller for village dehulling needs in Botswana	PRL dehuller	Tested PRL dehuller Changed design to give batch and continuous operation Reduced size to accommodate batch dehulling needs Changed design to facilitate local manufacture Test on sorghum on large scale	Dehuller adopted by user Milling industry established Dehuller manufacture established with export to other countries Improvement of local manufacturing capacity Good understanding of dehuller operation locally
Mini-PRL	Develop batch dehuller for small quantities of grain	PRL dehuller	Reduced capacity of PRL dehuller Batch dehulling incorporated Bran aspiration eliminated Tested on grains under lab conditions in Canada Lab testing in various African countries Extensive field testing in the Gambia Tests with various types of abrasive disks	Dehulled products acceptable to village women Viability of dehuller depended on management Interest generated in small dehullers Lab tests are not enough for village adoption Dehuller size appropriate for many rural environments Modifications needed to allow local manufacture and prolong machine life

Mini-CRS	Develop appropriate dehuller for Gambian villagers' needs; low cost, durable, batch processing of about 5 kg, easy operation	Mini-PRL	Mini-PRL tested in village Close collaboration with users Mini-PRL redesigned Design made simple, parts redesigned for local manufacture Mini-CRS tested to assess technicosocio-economic impact	Mini-PRL not durable for local use Mini-CRS durable and easier to operate Local manufacturing capability built Village management procedure being developed Possible use of dehuller in other countries in Africa Reduction of imported material such as clutch Mini-CRS is low cost and technically viable
Mini-ENDA	Develop appropriate dehuller for Zimbabwean village needs, low cost, durable, batch processing of about 15 kg	Mini-PRL	Surveyed dehulling needs Tested Mini-PRL Determined size of dehuller Mini-ENDA with several changes designed and built Village testing with strong user participation	Larger dehuller with hopper and trap door for emptying developed Reduced number of bearings Easier to manufacture Reduction of imported parts Easier to operate Village testing procedure being developed Large-scale dissemination of dehullers in Zimbabwe based on village lab results
Mini-SISMAR/ ISRA I and II	Develop dehullers for local manufacture and village use in Senegal; batch size less than 7 kg, economical in operation, with winnowing	Mini-PRL	Survey of dehulling needs Mini-PRL in lab. Design changes made to incorporate winnowing Mini-SISMAR/ISRA I tested in villages. Results of field testing used to develop Mini-SISMAR/ISRA II Commercialization activities initiated	Design of Mini-SISMAR/ISRA I and II. Prototype I suitable for batches over 4 kg. Prototype II has hopper, can dehull two batches less than 4 kg simultaneously, incorporates trap doors for emptying, cost reduced compared to type I Both prototypes I and II can dehull and winnow different batches of grain at same time Production line being set up for manufacture of Mini-SISMAR/ISRA II and anticipated large-scale manufacture for Senegal and other African countries Expected improved milling of grains in Senegal

- Local manufacturers must be involved during all phases of the design if the designer does not have suitable production facilities.
- Prototype dehullers must be tested during the design phase both to optimize their performance and to expose the designer to problems that will be encountered by the user.
- The prototype dehuller should be tested under local user conditions to obtain feedback for any necessary modifications.
- The prototype should be tested over long periods to assess its durability, maintenance problems, and technical acceptability.
- Special consideration should be given to the availability of spare parts, the technical expertise of the operator, the local availability of technical support for maintenance and repairs, and ease of operation.

Although these points are not exhaustive, they do encompass the prerequisites for obtaining an appropriate design. The first six questions should be considered before embarking on any hardware design and it is important that the designer obtain satisfactory answers through collaboration, with a socioeconomist for example. Even though a piece of equipment may be technically perfect, its design is not considered appropriate if it is not used because of high cost, high technical sophistication, or lack of social acceptability. Experience suggests that a deliberate effort to consider these questions and points should contribute to the development of useful dehuller designs.

CHAPTER 5
GRAIN–MACHINE INTERACTIONS

The dehulling action in the abrasive-disk dehuller arises from the contact between an individual grain and a moving abrasive surface. This chapter's first section discusses the important grain characteristics that determine whether a grain can be dehulled. Then, traditional dehulling is discussed in terms of grain characteristics, and some key definitions are introduced that relate to objective measurements and subjective judgments concerning dehulling. The next section moves from a focus on the grain to a focus on the abrasive disks: the key factors that affect the disk's ability to dehull are discussed. Grain–disk interactions are examined next and, finally, dehuller performance and its objective measurements.

GRAIN CHARACTERISTICS

Structure of the grain

The science of cereal chemistry has delved deeply into the grain structure of sorghum and has begun to explore that of pearl millet. If a sorghum or pearl millet grain is cut along its length (Fig. 21), three main parts can be distinguished: the pericarp (outer covering), endosperm (starchy part), and germ (oily part) (Sullins and Rooney 1977; Rooney and Miller 1982; Rooney and Murty 1982).

The pericarp — known in milling technology as bran — contains, at best, fibre and very few or no nutrients and, at worst, antinutritional materials. Thick pericarps tend to adhere loosely to the kernel, thin pericarps tightly. The degree of adhesion affects the ease of both traditional and machine dehulling.

Immediately below the pericarp, but usually not visible in cross section, some sorghum genotypes have a coloured layer called the testa or subcoat. The colour of the testa can vary from brown to purple among different varieties, and testa thickness can also vary. The colouring is associated with a high concentration of polyphenols (also called biologically active phenolics, tannins, or tannin-like substances (Hulse 1980)) that inhibit the body's ability to digest the grain protein. Traditional practice is to dehull the grain until most of the testa is removed.

The endosperm consists of two visibly distinguishable components: the corneous endosperm (also referred to as hard, flinty, horny, or vitreous endosperm) and the floury endosperm. The relative proportions of corneous and floury endosperms defines the kernel texture or endosperm texture and plays a major role in determining grain quality and food quality. The endosperm contains starch and protein. The amount of corneous endosperm largely defines the grain's ability to withstand traditional hand stamping or pounding; it resists crushing. The larger the corneous portion, and conversely the smaller the floury portion, the fewer broken kernels will be found in a traditional mortar at the end of the pounding.

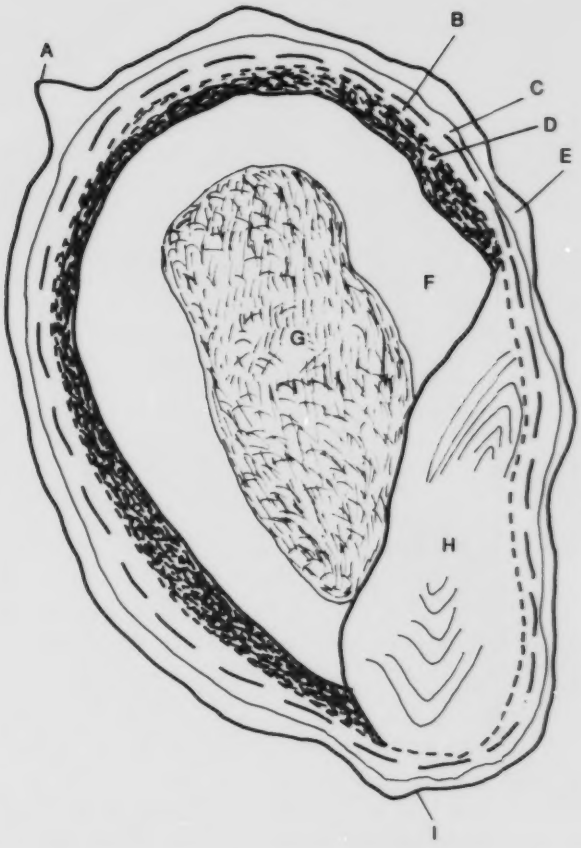

Fig. 21. Cross-section of sorghum grain. A, stylar area; B, aleurone layer; C, testa; D, peripheral layer; E, pericarp; F, corneous endosperm; G, floury endosperm; H, germ; and I, pedicel.

The germ contains oil globules, protein bodies, and only a few starch granules. The germ of some cultivars is deeply embedded in the endosperm and is difficult to separate, whereas in others it protrudes and separates easily from the kernel. Pulverized germ in sorghum flour, because of the fat content, limits the shelf life of flours even if they have been produced by a totally dry dehulling and milling process. However, a flour that contains portions of the germ is more nutritious.

Endosperm texture

A numerical rating scale has been developed for endosperm texture. The rating is derived from visual examination of half kernels cut along the long axis. The rating ranges from 1 to 5 where a rating of 1 means that the kernel contains very little floury endosperm (almost completely corneous) and a rating of 5 means essentially all floury (Rooney and Miller 1982). (The French language literature on

the subject reflects a similar rating range, known as the Bono Scale, but assigns the number 0 to all-floury and the number 4 to all-corneous.)

More research is needed to discover how closely this measure of endosperm texture correlates to certain groups of preferred food end products. The relationship of traditional dehulling to endosperm texture has been reported by Kante et al. (1984) for some pearl millets and by Scheuring et al. (1983) for some sorghums. General experience indicates, however, that sorghum with endosperm so soft that it merely pulverizes under mortar and pestle action can be successfully dehulled by abrasive-disk dehullers.

Dehulling

The objective of dehulling is to remove all the pericarp and testa layers of the grain with minimal loss of endosperm and germ, and to achieve this with a minimum of energy and time. Because proportions by weight of these components vary between (and within) sorghum and millet varieties (Table 7), the degree of dehulling required varies from variety to variety.

For example, the proportion of pericarp ranges from 3 to 11% of kernel weight (Table 7). Thus, the "edible" portion of the kernel — the endosperm and germ — varies between 97 and 89%. An ideal dehulling process would therefore remove,

Table 7. Relative proportions (% of kernel weight) of pericarp, endosperm, and germ in some types of sorghum and millet kernels.

	Pericarp (%)	Endosperm (%)	Germ (%)	Theoretical yield (%)
Thick pericarp sorghum	6.0	84.0	10.0	94.0
Thin pericarp sorghum	3.0–5.0	90.0	5.0–7.0	95.0–97.0
Large pearl millet	7.0	76.0	17.0	93.0
Medium pearl millet	7.5	75.0	17.4	92.5
Small pearl millet	10.6	74.0	15.5	89.4

Source: Adapted from Rooney and Miller (1982) and Faubion et al. (1985).

Table 8. Effect of pericarp thickness on manual dehulling time of some sorghum cultivars.

Grain type	100-kernel weight (g)	Endosperm texture	Pericarp thickness	Average dehulling time (minutes)	Endosperm recovery (%)
Nio Fionto	43.8	3	very thick	11.0	66.3
Malian Guineense	21.8	2	thick	19.4	71.7
Malian Guineense	21.3	2	thin	26.4	68.6
Voltaic Guineense	20.1	2	thick	20.0	–
Voltaic Guineense	20.6	2	thin	29.0	–

Source: Scheuring et al. (1983).

for instance, only the 6% by weight that constitutes the pericarp of the first sorghum sample listed in Table 7.

In traditional mortar-and-pestle dehulling, the addition of water (300 g/kg of grain) causes the pericarp layer to swell and reduces its adherence to the kernel. Subsequent pounding of the grain with the pestle abrades and shears the pericarp from the kernel.

Pericarp thickness and its adhering properties affect the amount of manual effort required for dehulling. In experiments in West Africa with sorghum, one woman pounding at an average rate of 60 strokes/minute dehulled 2-kg batches of grain (Scheuring et al. 1983). She stopped dehulling when she judged that the sample had been adequately dehulled (Table 8). Dehulling time differed significantly between very thick, thick, and thin pericarps. "Because of the tiring effects on the woman" (she could only dehull six samples per day), the experiment was limited to 20 batches of 2 kg.

Definitions

The literature on dehulling reflects some confusing, and at times conflicting, use of terminologies. For clarification, the paragraphs that follow define some of the terms in common use (also see Appendix A). (Although the data in Tables 7 and 8 came from different sources, combining them makes it possible to illustrate the definitions.)

Theoretical yield is the kernel portion (in percentage by weight) that represents the edible or acceptable component. For sorghum and pearl millet, theoretical yield equals 100 minus the percentage of pericarp (Table 7, last column).

Yield is the proportion (in percentage by weight) of dehulled grain relative to the original weight of the undehulled grain. The term "endosperm recovery" is used by some writers, and has the same meaning as yield. Yield merely indicates the relationship between the amounts of dehulled kernels and of abraded fines. It does not, for instance, indicate whether a particular sample has been dehulled too much or too little.

Extraction rate is that level of yield that is judged to be acceptable to the user. Because, in the example of Table 8, the woman continued to dehull until she had reached a level acceptable to her, the reported endosperm recovery of 66.3% for the samples of Nio Fionto constitutes the extraction rate, the acceptable yield.

Dehulling efficiency is the ratio of the theoretical amount of kernel that must be removed to the amount that actually is removed to achieve "total" pericarp removal. This concept of dehulling efficiency is difficult to understand, and may best be illustrated by a specific example. Table 7 presents a range of theoretical yields. If a typical value of theoretical yield is 90% (Table 7) and the extraction rate, as judged by the woman doing the pounding, lies around 30% (Table 8), then she has removed three times as much material as was theoretically necessary before she was satisfied that all the pericarp (10% by weight) had been removed. The dehulling efficiency in this case is calculated as follows:

$$\begin{aligned}\text{dehulling efficiency (\%)} &= [(100 - TY)/(100 - ER)]100 \\ &= [(100 - 90)/(100 - 70)]100 \\ &= 33\%\end{aligned}$$

where TY is the theoretical yield and ER is the extraction rate.

The ratio is useful as an objective measure of the dehullability of different grains and grain legumes. It permits grains and techniques to be compared. For example, the dehulling efficiency of the Mini-PRL dehuller on a range of grain legumes is reported in Reichert et al. (1984b).

Practical measurement of extraction rate

In traditional dehulling, the extraction rate is determined by a subjective evaluation of the dehulling end point. The women who daily hand dehull are accustomed to the properties of a limited range of local grains or grain legume varieties. Those women have developed the experience to judge by eye and by feel how far they need to dehull manually so that the cooked end product will be acceptable to them and their families. Although subjective, this measurement nonetheless results in very consistent and reproducible values of extraction rate.

Are there objective, measurable variables that can reproduce the woman's judgment? To what degree are these objective measures transferrable, say, from Burkina Faso to Malawi?

Scientists have tried several objective measurements, which include flour colour, fibre content, and polyphenol content. The flour from coloured sorghum, whether it contains tannin or not, becomes lighter coloured as more material is removed. However, the complex interaction among consumer preferences for particular food end products, varietal variations, differences in local agroclimatic conditions, and the range of grain-quality parameters exhibited by the varieties have inhibited the development of any universally applicable objective measures.

Practical experimentation is, however, possible in each locality. The homemaker, when presented with samples of one variety (the one with which she is familiar) dehulled to different yield levels, will consistently select that sample that most closely resembles how much she would remove by mortar and pestle. The measure of a mechanical dehuller's effectiveness reduces then to the comparison: how much material does the dehuller have to remove to be acceptable to the consumer? Fine tuning of the mechanical dehuller's performance can then be done to ensure that it causes no greater "waste" than does manual dehulling. In the absence of a sufficient and definitive method for determining the dehulling end point, the owner of a mechanical dehuller is advised to seek the advice of a local woman. Her judgment is the most reliable "instrument" that exists at the moment.

Abrasive disks

Having considered the characteristics that affect how prone the grain is to effective dehulling, let us turn to the abrasive component that is the active agent of the mechanical dehuller. The factors that affect the abrasive disk's ability to dehull are surface area, speed, and composition (type of abrasive material used). The first two factors, surface area and speed, are easier to describe than is composition.

As the amount of abrasive area available increases, clearly the amount of abrasion will also increase. The mechanical dehuller's rotor is, therefore, composed of many disks or wheels, separated by spacers, to present a large total surface area.

The relative speed between the disk surface and the (relatively stationary) grain also affects the rate of grain abrasion. Increasing the disk's rotational speed

increases the disk surface speed. The results of work with the tangential abrasive dehulling device (TADD) indicate a linear relationship between disk rotational speed and abrasion rate for sorghum and wheat (Reichert et al. 1986). As well, the portion of the disk farthest from the centre moves at the greatest speed and, therefore, provides most of the dehulling action.

Abrasive-disk composition

Previous chapters indicated that two different types of abrasive disk have been used in the dehullers: grinding stones (or wheels) and resinoid cut-off disks (used in the metal industry for grinding and for cutting metal). Because both the wheels and the disks are circular, they are usually referred to as abrasive disks. Generally, resinoid disks have a gentle, selective action that provides relatively slow rates of removal of kernel material, whereas grinding wheels can be selected to exhibit the full range of very slow to very rapid removal of kernel material.

A grinding stone (and resinoid disk) suitable for abrasive removal contains many sharp pieces of a hard material, grit, that are held together by a bonding agent. When a moving piece of grit (protruding from the bonding agent) comes into contact with a stationary, much softer, grain kernel, it takes a "bite" out of the kernel. A large, long protrusion will take a "deep" bite. The physical size of the grit thus affects dehulling efficiency; a deep "bite" may remove portions of both pericarp and endosperm, whereas a shallow "bite" may remove only a portion of the pericarp. Laboratory studies have reported on the interaction between various abrasive types and a range of sorghum varieties in terms of rate and quality of kernel abrasion (Reichert et al. 1982; Reichert et al. 1984a; Reichert et al. 1986; Mwasaru et al. 1988).

The abrasive disks also wear away, although much more slowly than do the kernels, and will need to be replaced periodically. Results on RIIC's first prototype (RIIC 1980a) showed an average reduction of 27% in the weight of the abrasive grinding wheels after 500 t of sorghum had passed through the machine. The grinding wheels became thinner with wear, particularly at the periphery.

The wear is explained by two mechanisms. First, attrition dulls the cutting points of the grit and, second, fracture wear causes the grit to fracture or to tear out of the bond as a result of stresses on the cutting points. Fracture wear results in new cutting points being formed or new grit being exposed from slightly deeper in the grinding wheel. The nature of the fractures, inherent in the specific abrasive material, must result in a sharp edge or point to maintain the abrasive power of the wheel. A rounded or smooth break would result in a dull surface with diminished abrasive ability.

Thus, the type of abrasive material chosen is important, and the following basic principle applies. The composition of such a self-sharpening grinding wheel is selected in relation to the hardness of the material being ground — in this case the grain. The correct composition is achieved when the abrasive material, the individual piece of grit, falls out of the bond just after it has become sufficiently dull to warrant replacing.

The science of grinding wheel composition and manufacture is complex. Briefly, however, the key descriptors for specifying abrasive disk composition are type of abrasive (silicon carbide or carborundum, i.e., aluminum oxide), grit size,

grade (proportion of bonding material), structure (a measure of density), and bonding material. A typical specification by one manufacturer would be A 36 L 5 VBE (Norton Company 1975). (Further details about grinding wheel composition are given in Appendix B.)

In applications such as metal grinding, only the peripheral circumference of the grinding stone is used. For dehulling food grains, however, both the wheel periphery and the wheel face (side) are used because the wheel is immersed in the grain. Thus, the manufacturer has to be instructed to also surface dress the wheel face to remove the excess bonding material.

In using grinding stones to dehull grain, the most important characteristics appear to be surface dressing, grit size, and grade. Of lesser importance seem to be structure, bond modification, and abrasive type (Mwasaru et al. 1988).

Grain–Disk Interactions

Extensive research on the interaction between various grinding stones and individual sorghum and millet kernels has been done in Canada at PBI of NRCC in conjunction with the University of Saskatchewan (Mwasaru et al. 1988).

In one experiment, the effect of grit size on extraction rate was determined on high-tannin sorghum grain (Table 9). Extraction rate in this case was taken as the yield of dehulled grain when the tannin content remaining in the kernel was 0.5%.

Two conclusions can be drawn from these data:

- The finer the grit, the less material must be removed to achieve the acceptable yield criterion, i.e., the higher the dehulling efficiency, and
- Hard sorghum (very vitreous) is dehulled more efficiently than is soft sorghum.

The practical conclusion that a miller can draw from this example is that relatively small changes in grit size can have a significant effect on the operations in terms of acceptability of the dehulled product to the customer and in terms of the cost to the customer.

Experience in rural Tanzania with a 3- to 4-t lot indicates that the soft endosperm, tannin-containing *Serena* variety can be adequately dehulled with 60-grit stones at 2 000–2 400 rpm. A yield of 85% seemed to be acceptable to the consumer, and most of the dehulled kernels were reported to have been intact after leaving the dehuller. A more meticulous repetition of the experiment is, however,

Table 9. Effect of grit size on extraction rate (%) of soft and hard high-tannin sorghum.

Grit size (mesh)	Soft sorghum	Hard sorghum
24 (large)	41.5	72.0
36	45.0	83.0
46 (small)	62.5	89.5

Source: Adapted from Mwasaru et al. (1988).

desired. A finer grit (i.e., higher number) may be necessary if the dehuller is expected to deal mostly with *Serena* material.

By contrast, the experience in a rural setting in Ethiopia indicated the need for coarser grit. The 60-grit stones performed well on the local sorghum and maize being presented. The women, however, also brought barley for dehulling because hand pounding of this hard grain was even more difficult and time consuming. The 60-grit stones were effective with barley only if each batch was processed twice. However, substituting stones with a combination of 54- and 46-grit provided acceptable dehulling on a single pass.

DEHULLER PERFORMANCE

The preceding sections have reviewed the grain–machine interaction at the level of the individual kernel. This section looks at grain–machine interaction at the batch level, moving from the topic of abrasive material effectiveness to examine dehuller effectiveness, or dehuller performance.

Quantitative measures of performance

Three measures of quantitative performance are in common use: throughput or input (in kg/hour), output (in kg/hour), and yield (as a percentage). Throughput refers to the whole, undehulled material, and output refers to the whole dehulled kernels. For example, the capacity of an RIIC dehuller may be reported as being a throughput of 600 kg/hour and an output of 450 kg/hour. We can then infer that 150 kg of abraded fines were produced, and that the yield was 80%, or [(output/throughput) × 100].

In comparing different dehuller designs, it is important to report any two of the three measures (throughput, output, or yield); one measure alone is not sufficiently informative. Thus, the statement "this dehuller can achieve a throughput of 600 kg/hour at an 80% yield" is informative.

Important complementary facts that need to be reported are how much energy (kilowatt-hours or litres of diesel fuel) is required to achieve a given performance rate and how many hours of labour for the mill staff does this represent.

It is also important to examine the dehulled portion carefully, and report the percentage of broken kernels. The greater the kernel breakage, the poorer is the dehulling efficiency, because endosperm material is being exposed to the abrading surface, resulting in poor recovery of the kernel's food portion. Thus, the level of broken kernels must be minimized by selecting the optimum abrasive coarseness and optimizing the shaft rotational speed.

Typical performance rates

The small dehullers — the Mini-PRL, Mini-CRS, Mini-ENDA, and Mini-SISMAR/ISRA — have a throughput capacity in the range of 200–600 kg/8-hour day, at an extraction rate of 80%. The Mini-PRL and the Mini-CRS, at the lower end of this scale, must be emptied by tipping each batch. The Mini-ENDA can be emptied more quickly through the trap door. The Mini-SISMAR/ISRA and the RIIC dehullers are capable of either batch or continuous operation. A slow flow-through rate achieves higher removal rates

Table 10. Typical performance rates of the RIIC dehuller on Botswana cereals.

	Output (kg/hour)	Extraction rate (%)
White sorghum	500	85–90
Red sorghum	400	80–35
High-tannin sorghum	225	75–80
Maize	500	85

Source: RIIC (1980b).

(lower yields), a fast flow rate achieves lower removal rates (higher yields). In its operator's manual (RIIC 1980b), RIIC gives some conservative guidelines of performance expectations with the grain types that are commonly found in Botswana (Table 10). The white varieties had a high proportion of corneous endosperm, the reds had a lower vitreousity, and the "high-tannin" sorghum varieties were probably (by international standards) low-tannin varieties with medium vitreousity.

Uniformity of dehulling, using mechanical or traditional means, is another important qualitative, visual measure of performance. It indicates the degree of variability in dehulling among individual kernels. With certain coloured sorghum, some field investigators have indicated dissatisfaction over nonuniform dehulling with the Mini-PRL dehuller. Moving the outside disks as close as possible to the end plates seems to solve the problem.

Summary

The operator of the abrasive-disk dehuller can control several variables to optimize the interaction between the dehuller and the grain. Some of the variables, although adjustable in theory, are time consuming to change in the presence of customers' pressure for results. Ranging from the most flexible to the least, these are:

- The dehulling time is entirely under operator control. It affects the yield rate achieved and the throughput rate and, therefore, income for the mill.
- Aspiration rate can be altered relatively quickly to ensure that most abraded fines are removed with the RIIC dehuller or Mini-SISMAR/ISRA type. With those mini-variants that have no aspiration, a build-up of abraded fines in any one batch can cause dehulling effectiveness to decrease, necessitating a second pass. A separate stage of winnowing, either manually or mechanically, has to be built into the work flow.
- Speed of the abrasive disks can be controlled. If the dehuller is driven by an engine, a simple fuel-flow adjustment is required but, if the dehuller is driven by an electric motor, then the pulley on the dehuller shaft must be changed, taking at least 30 minutes. Mill operators tend instead to stay with one "best" speed, suitable to most of the commodities being brought in.

- The type of abrasive disk can be changed but the physical replacement of a set of abrasive disks can require up to 1 day, and the operator also incurs a cost (the equivalent of 45–250 USD depending on the type and number of abrasive disks, import duties, and availability) when purchasing each set of differing composition. In practice, some preliminary experiments should lead to one composition that is best suited to the range of materials being brought to a specific mill.

CHAPTER 6
SMALL-SCALE MILLING SYSTEMS

In practice, abrasive-disk dehullers can, if deployed effectively, meet the needs of both urban and rural populations. Several of these machines have been installed and used in various countries in Africa, as outlined in Chapter 3. With the exception of mills in Botswana, where operating experience has been continuously acquired and well documented over several years with the RIIC dehuller, information on mills using the mini-dehullers has not yet been extensively documented, mainly because field experience is only now being acquired using these machines. Nevertheless, useful knowledge that can be used to develop guidelines for installing, operating, and maintaining them and for assessing their overall performance can be inferred from the installations now in operation in various countries.

This chapter is concerned with small-scale milling systems that can be installed using the dehullers as main components of the mills. These mills are characterized by the use of a single dehuller–grinder combination to process small quantities of grain brought by individual clients (service milling) and may concurrently process quantities that are packaged and sold to clients (trade milling). However, because the rural client prefers to bring her own grain for processing, service milling is emphasized. Using the experience gained in existing small-scale milling installations that operate on batches, we attempt to point out the important requirements for installing, operating, managing, and evaluating these milling systems in both village and urban areas. Although this chapter is not intended to be a "handbook" on rural small-scale mills or a compilation of case studies, it will be useful to persons interested in introducing such milling systems in various countries in Africa. The overall experience gained during the operation of small-scale milling systems using the abrasive-disk dehullers will be documented in the near future once adequate information is collected in various countries.

PLANNING SMALL-SCALE MILLS

Small-scale mills can use either the RIIC, Nuhull, or mini-dehullers, which have capacities of up to 15 kg, depending on the machine, when operating in the batch mode. Initial considerations are, therefore, based on the size of the machine best suited to a given locality, accounting for economic viability of the installation. Steps that can be used to plan and implement a continuous-flow, industrial-type mill have been elaborated by Eastman (1980). Some of the ideas presented there are used here to define the sequence of events that should be considered before a small-scale rural mill is installed.

Identification of grain-production areas

One of the first considerations in the planning of a mill is the obvious need to determine what types of grains need to be dehulled and what is their role in the diet of the people; what quantities are produced and what is the typical production per farmer; and what quantities are produced versus quantities consumed?

Data will also be needed to estimate future production and the number of potential users in the area.

Determination of grain consumption

Quantities of grain consumed per person should be determined through surveys of a sample population. In addition, the main methods of processing the grain and of food preparation should be documented taking taste preferences into account. For example, it would be unwise to install a mill if grains are not traditionally dehulled or if consumers are generally not enthusiastic about dry dehulling and grinding. Furthermore, the quantity of grain consumed each day should be assessed as this will determine the average batch size, which is directly related to the energy required for processing and the cost of dehulling. It would also be useful to obtain information on the amounts of grain eaten during certain celebrations, holidays, etc., so as to estimate peak dehulling needs; users would not be content if the mill could not process their grain during these peak periods.

Choice of milling territory

The milling territory is the area that will be served by the mill. Its size will depend on the capacity of the installed dehuller and grinder, the main criterion being that of having a mill that will have enough throughput to make its operation economical. To assess the economic viability of the mill, the approximate quantity of grain that will be milled on a daily basis and the cost of processing 1 kg should be determined before the mill is installed. This and the estimated daily consumption per person would give the number of persons who need to patronize the mill to ensure a certain profit margin. Using simple surveys, it should be possible to estimate the size of a village or a group of villages that the mill can service. It should be mentioned that it is better to have too many people patronizing the mill than not enough.

The proximity of mills to one another should be considered as this can adversely affect the economic viability of one of them. This may occur if one of the mills, for some reason, charges higher processing fees. Women close to this mill may decide to use another mill, depending on the distance between them. Even if distances are appreciable, they may use local transport to carry their grains to the cheaper mill and carry out other errands on the same trip so as to justify the transport costs. Thus, mills charging different prices for processing are best located sufficiently far apart.

Establishing users' willingness to use a mill

A survey would be needed to determine women's reactions to establishing a grain mill. Information should also be obtained on the availability of cash to pay for machine dehulling. Results of this survey (using simple questionnaires and a small representative sample of the population) would indicate if homemakers are willing and able to patronize the mill.

Comparison of products of traditional and machine milling

Whether the mill is patronized or not will depend on the quality of its products compared to those obtained using traditional methods. To ensure that a fair comparison is made, the same variety of grains should be dehulled traditionally to the users' satisfaction and this degree of dehulling duplicated by the dehuller. Several women in the milling territory could be asked to give their opinions of these dehulled samples. The users must accept the machine-dehulled product before a mill is installed.

Choice of site for mill

The location of the site for the mill depends on several factors.

- The site should be accessible to all the potential users within the milling territory.
- If the mill belongs to a community, it is preferable to install it on community land rather than on that of an individual.
- The site should be in a village where there is strong leadership and the people are progressive and open to change.
- The physical relief of the site should be such that construction costs are minimized. At the same time, the land area should be large enough to accommodate the mill.
- To minimize noise and exhaust pollution from the engine, the mill should be located far from homes.

Funds for setting up mill

Funds to meet the capital costs — construction of the building, purchase of equipment, installation, and start-up — may be obtained from various sources such as community contributions, government support, bank loans, and development agencies. Mills for village operation are often funded by development agencies because of the lack of cash in villages. Experience has shown, however, that the users are more enthusiastic if the village community pays at least the cost of the capital equipment over several years.

All financial transactions and contributions by all those concerned should, within the social context involved, be recognized and formally recorded for future reference. Such actions will discourage individuals or groups of people from claiming the mills as their personal property.

TYPICAL INSTALLATIONS

A typical service mill consists of an abrasive-disk dehuller, a grinder, a diesel engine or electric motors, and a winnower if needed. The physical size of the mill depends on the type of equipment used and the scale of operation.

Building materials and space

Building materials used range from mud to cement, but it is important to have a structurally sound building that is well ventilated with ample working and storage

space. Materials and construction techniques used should account for the vibration of equipment during operation.

An example of the physical structure of typical mills used in the Gambia is shown in Figs 22 and 23. In this case, cement bricks are used to construct the walls of the building, the roof is made of timber and corrugated iron sheets, and the working space is partially surrounded by wire mesh (Fig. 23) to provide adequate ventilation and keep out intruders. In some mills in Senegal, the walls of the building are constructed from corrugated iron sheets.

Because of the prevailing conditions in various locations regarding the availability of land space, equipment size, funds, storage space, etc., the sizes of mills may differ. It is, however, important to have adequate work space around equipment for safe operation and maintenance. The size of the building depends on the size of the dehuller used and whether trading or service milling is carried out. Mills using mini-dehullers are smaller than those using the RIIC machines whereas mills for trade milling need more storage space compared with service mills.

Equipment layout and installation

A typical layout of mill installations in Botswana using an RIIC dehuller (Fig. 24) has a diesel engine, located outside the work area, to power the dehuller and grinder. Layouts used for the Mini-CRS in the Gambia are shown in Figs 25 and 26.

In Fig. 25, the dehullers and grinders are powered by two separate electric motors whereas the installation shown in Fig. 26 uses a single diesel engine to power both machines. In the Gambian installations, a winnowing room is an important feature of the mills because the Mini-CRS dehuller does not have a winnower incorporated in its design.

Mills using an RIIC dehuller are usually powered by a 20- to 25-hp diesel engine that is installed in a separate room outside the working area to minimize

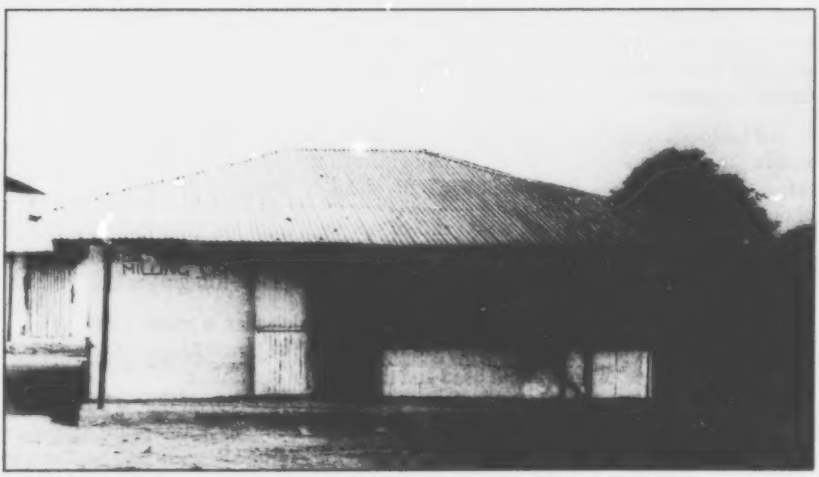

Fig. 22. Typical building that houses milling equipment in the Gambia.

noise (Fig. 24). Power is transmitted to the dehuller and grinder through an intermediate shaft that can be mounted on the wall separating the engine room and the work space, a method found to be effective in installations in Botswana (Fig. 27). V-belts are used to transmit power from the engine to the intermediate shaft and then to the dehuller and grinder. All the machines are firmly mounted on the floor using rubber shock-absorbers to reduce the effects of vibration.

An electrically powered mill can use 3- and 7.5-hp motors to run the Mini-CRS dehuller and grinder respectively. Figure 28 shows the simple installation required, where the motor and dehuller are mounted on an angle-iron frame and connected by a V-belt. Adequate working space is provided between the dehuller and grinder assemblies (Fig. 25). Electrically powered mills are not subjected to excessive vibration and do not produce as much noise as a diesel engine-powered mill.

In the diesel engine-powered mill using the Mini-CRS dehuller, the 11-hp engine is mounted on a frame (Fig. 29), between the dehuller and grinder, with power being transmitted by V-belts and pulleys. This arrangement ensures that the whole unit is properly mounted and aligned in the workshop before being brought to the village. Although there are advantages to this method of mounting, there are instances when this arrangement is not practical because of excessive engine vibration, then the machines must be mounted on different frames.

Although certain basic engineering guidelines must be followed during the installation of equipment in mills, it is not always possible for all mills using the same type of equipment to have identical physical arrangements. First, because electric motors are cheaper than diesel engines, the former are advisable for

Fig. 23. Mill partly surrounded by wire screen.

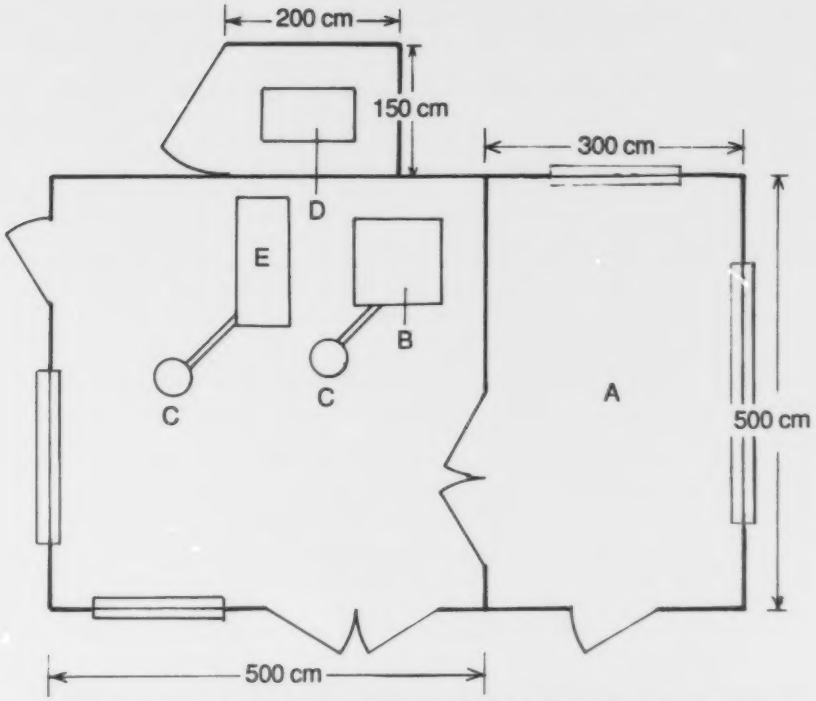

Fig. 24. Sample floor plan for a mill using an RIIC dehuller (from Eastman 1980). A, storage area; B, RIIC dehuller; C, cyclones; D, engine; and E, grinder.

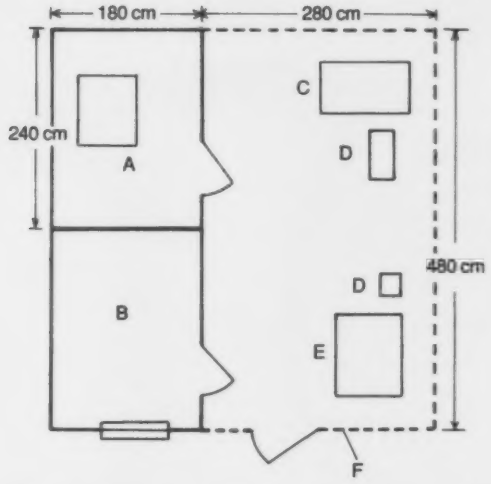

Fig. 25. Typical floor plan for mills in the Gambia using a Mini-CRS dehuller and electric motors. A, winnower; B, storage area; C, grinder; D, motors; E, dehuller; and F, wire screen.

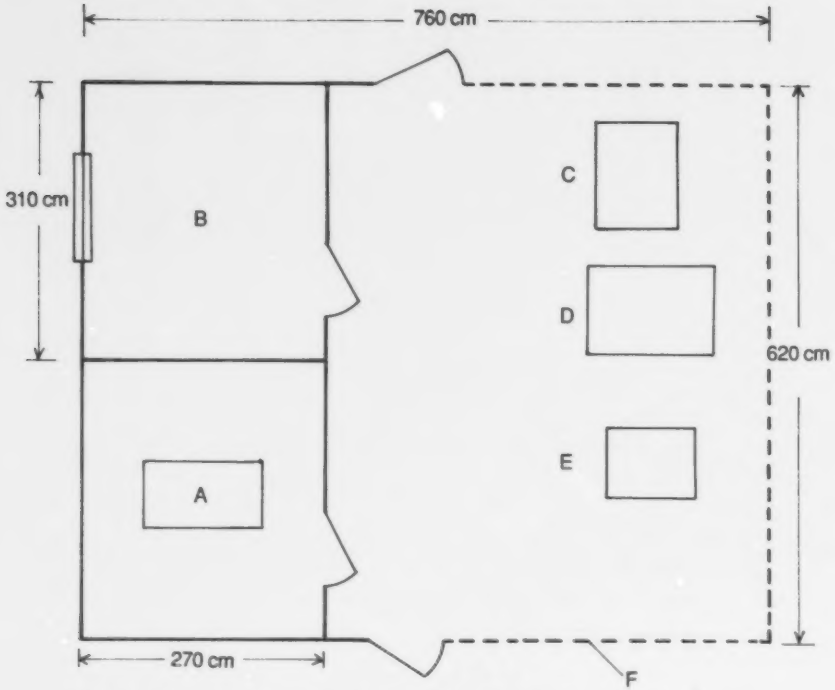

Fig. 26. Floor plan for a mill using a Mini-CRS dehuller and a diesel motor. A, winnower; B, storage area; C, grinder; D, engine; E, dehuller; and F, wire screen.

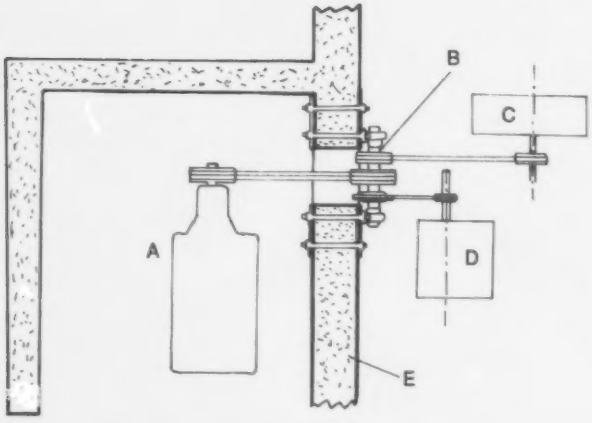

Fig. 27. Method of connecting the RIIC dehuller and grinder to the diesel engine through a wall-mounted intermediate shaft (courtesy of RIIC, Botswana). A, diesel engine; B, intermediate shaft; C, grinder; D, dehuller; and E, wall.

Fig. 28. The Mini-CRS dehuller powered by an electric motor.

Fig. 29. A mill using a Mini-CRS dehuller, a grinder, and an engine.

powering mills if a reliable electricity supply is available. Second, a larger electric motor may be judged more convenient to operate both the dehuller and grinder instead of two motors. Third, where a dehuller is incorporated into an existing mill that uses a diesel-powered grinder, it may be necessary for the dehuller to have its own diesel motor. Such a situation will exist where the power of the existing diesel engine is insufficient to operate both the grinder and dehuller.

The use of more than one power source needs to be considered carefully before installation. Two engines will increase the capital cost of the mill, but it may have benefits in the case of breakdowns when the mill cannot afford to stop operating. A small mill may not need to have both the grinder and dehuller in operation at the same time, in which case the use of two appropriately sized engines may be considered.

In some countries, such as the Gambia and Senegal, many grinders are already operating without a dehuller. In the Gambia, the Mini-CRS dehuller, which does not have a winnowing system incorporated in its design, is added to the existing 11-hp diesel engines powering the grinders. In Senegal, by contrast, the Mini-SISMAR/ISRA dehuller, which has a bran-separating system with its own 6.5-hp engine, is operated independently of the engine powering the grinder. Whatever may be the situation, the compatibility of equipment should be considered before purchase and installation to ensure that power requirements are met, direction of rotation of engine corresponds to that of dehuller and grinder, and the system is economically viable. In the absence of technical expertise and information on various components of a mill, experience shows that it is better to purchase a mill sold as a package.

The role of clutches in mill installations must be mentioned specially. Mills using the RIIC dehuller need a lever mechanism connected to the engine clutch so that an operator inside the mill can quickly disengage the operating equipment from the engine located outside. A dehuller using an electric motor does not need a clutch because the motor can be easily switched off. A typical mill in the Gambia has a Mini-CRS dehuller (with a clutch) and a grinder connected to an engine. When the engine is in operation, both the dehuller and grinder are in motion but the dehuller can be stopped by disengaging its clutch. The grinder is stopped by shutting off the engine or disconnecting the V-belt to the engine. The ideal situation would be that the dehuller and grinder each has a clutch, but this would substantially increase the cost of equipment. In installations in Senegal, the Mini-SISMAR/ISRA I dehullers use a clutch incorporated in the engine to allow the dehuller to be stopped before it is opened whereas the Mini-SISMAR/ISRA II dehullers use no clutch (see Chapter 4). Thus, in practice, various options are available regarding the installation of clutches, their use depending on the required operation and equipment design.

Safety and health standards must be considered. However, it has been observed that mills have failed to respect these standards. Some of the precautions are related to moving parts, noise, engine exhaust fumes, and bran and flour dust.

- All moving parts on machines must be covered to prevent parts of the body or clothes from being caught in them. Many installations are being run with bare V-belts and rotating elements, the excuse often given for this being that mill personnel do not get close to them during operation, that clients are not allowed near the machines, and that covering them up would increase costs.

Although no accidents have been reported so far, it is better to prevent them than risk having them.

- The noise of the diesel engines and the grinders (hammer mills) is considerable during operation. Prolonged use of them may cause hearing problems for the operator. Thus, ear protection is essential for mill personnel. This protection is lacking in present installations.
- Engine-exhaust fumes can be partly reduced by having the work area enclosed by a wire screen (Fig. 29), which permits good ventilation. It is, however, highly recommended for all engine gases to be exhausted through the roof or through the side of the mill.
- Bran dust pollution of the work area is minimized in installations using the RIIC, Nuhull, or Mini-SISMAR/ISRA dehullers by using cyclones attached to the dehuller (Chapter 4). In the case of Mini-CRS or Mini-ENDA dehullers, winnowing the dehulled grain and bran mixture using a hand-operated blower-type winnower causes bran dust to be spread all over the winnowing area. This has been improved by using an arrangement in which the hand-operated winnower is connected to an enclosed space sealed from the rest of the mill using canvas cloth (Fig 30). All the bran is collected in this space and emptied periodically. This arrangement unfortunately exists only in one installation.
- Flour dust from the grinder does not pose much of a problem. Nevertheless, it is recommended that all mill staff should wear masks during the operation of dehullers or grinders.

The installation of mills must, thus, be based on standard engineering practice. Because technical resources are often limited in rural environments, installation must be carried out using the manufacturer's recommendations, and skilled technicians or engineers to ensure safety, reliable operation, and conservation of financial resources.

Operation of mills

Various factors affect the operation of a mill, some of the important ones being proper choice of the mill's location, adequate number of clients, efficient mill personnel, good overall management, optimum operation of machines, low cost of milling, adequate inventory of spare parts, and satisfactory repair and maintenance. Observation of the operation of field installations shows that the smooth running of the mills using abrasive-disk dehullers cannot be assured if all of these conditions are not satisfactorily met.

Mill management

Mills with mini-dehullers can be satisfactorily operated using one operator (not necessarily literate) and a literate manager, but those with RIIC or Nuhull dehullers need two operators and a manager. It is useful for operators to have some technical background and they should be trained on the operation and daily servicing and maintenance of all the machines. They do not need to know how to repair the various types of equipment although this would be advantageous. In practice,

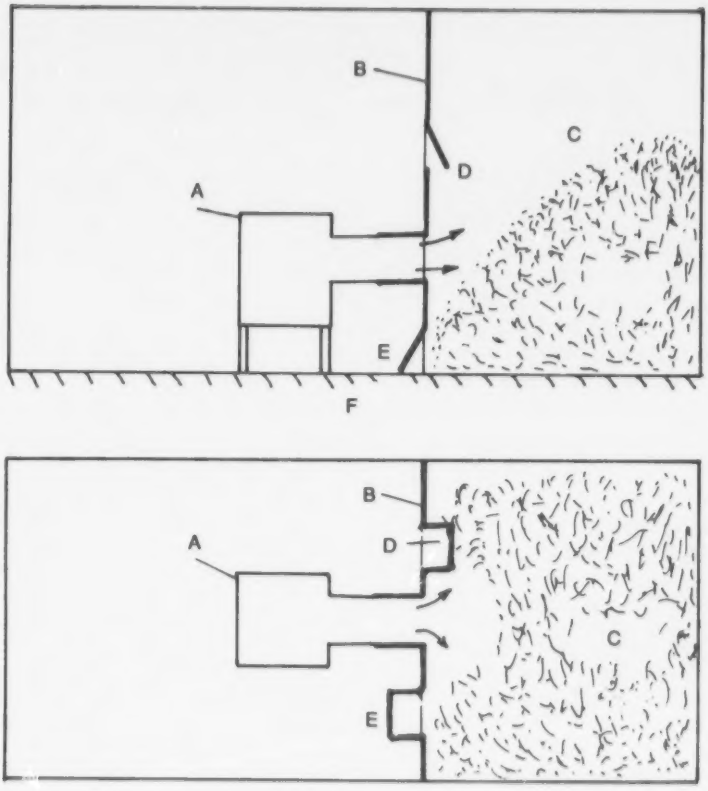

Fig. 30. Side view (top) and plan (bottom) showing the dust room (right) next to machine room containing the winnower (left). A, winnower; B, canvas wall; C, bran; D, flaps for observation; E, flap for emptying bran from dust room; and F, floor.

several hours of on-the-job training under supervision is all that is needed for operators to acquire adequate knowledge and confidence to operate a mill.

Mill managers are responsible for receiving the grains brought for processing, measuring them and receiving payment, recording pertinent processing data, and supervising the daily running of the mill. Operators are often male, because of the existing social structure in which women are not encouraged to operate machines. Women, on the other hand, serve well as mill managers as they understand the needs of the clients, who are female. We should point out, however, that nothing prevents women from operating the mills except social barriers, which are difficult to overcome.

In villages, the overall management of mills is by village committees chosen by the people. The structure and the method of choosing these committees depend on local customs, which are not the same even within a country from one area to another. In certain cases, the management committee consists of representatives from all the villages that use the mill. It has also been found useful to have an

executive committee that represents the larger management committee in the daily affairs of the mill; it meets monthly and reports once or twice a year to the management committee. All expenditures related to the operation of the mill must be approved by the executive committee, which fixes price and hires and dismisses mill personnel.

To have an effective committee, its members should be trained by qualified personnel from government or a development organization. They should be made aware of the importance of their responsibility, with the need to operate the mill economically being emphasized. Trainers of the executive committee need to encourage them to keep minutes of meetings, which will improve future accountability to the community. Financial statements are also kept by the treasurer. A bottleneck in the administration of this committee is the difficulty of, at times, finding a villager who is sufficiently literate to record decisions of the committee or important actions taken. In practice, however, it is often possible, in the absence of a literate villager, to co-opt an extension worker in the village.

Available results of field testing in the Gambia (Schoonmaker Freudenberger 1988) suggest that village committees need well-organized training and continuous follow-up for them to be effective. Failure to have such a committee affects the overall economic and technical viability and social acceptability of the mill. Some problems encountered in village-managed mills have been due to autocratic behaviour from one or more persons, dishonesty, and lack of interest by members. These shortcomings should be minimized by carefully choosing villages having management structures that have been successfully tested in similar activities.

Mills managed by an individual who is interested in making a living from the operation are, according to available results, better managed. Experience with grinders in various countries shows that those owned by individuals have been in operation longer and are more viable compared with village-owned machines, which experience frequent problems. A mill using a Mini-CRS dehuller and a grinder has been shown to be better managed compared with all the other village mills using this dehuller (Schoonmaker Freudenberger 1988).

Optimizing mill operation

Optimum operation of the abrasive-disk dehuller is assured by the operator, who should know the operating conditions for various grains. The ideal situation would be to use, for each grain and machine, the optimum speed of rotation of the disks for a given load of grain. This is not possible to implement in mills during normal operations, because of the complex relationship between amount of grain in the dehuller, disk speeds, dehulling times, and fuel consumption as shown, for example, in Figs 31 and 32 for *Souna* millet. The degree of dehulling rises as dehulling time, disk speed, and mass of grain are increased (Fig. 31), but the power used also increases (Fig. 32). Furthermore, these performance curves depend on the physical state of the disks. Therefore, in practice, the dehullers are operated at a fixed speed (1 500–2 000 rpm for the mini-dehullers and 1 500–2 400 rpm for the RIIC dehullers) for all grains, because these ranges of speeds give satisfactory dehulled grains at reasonable power consumption. Recommended ranges of operating speeds for various dehuller types are given by manufacturers.

It is customary for operators to dehull until a required yield is obtained. For sorghum and millet, the dehullers can produce this yield in 3–5 minutes, depending

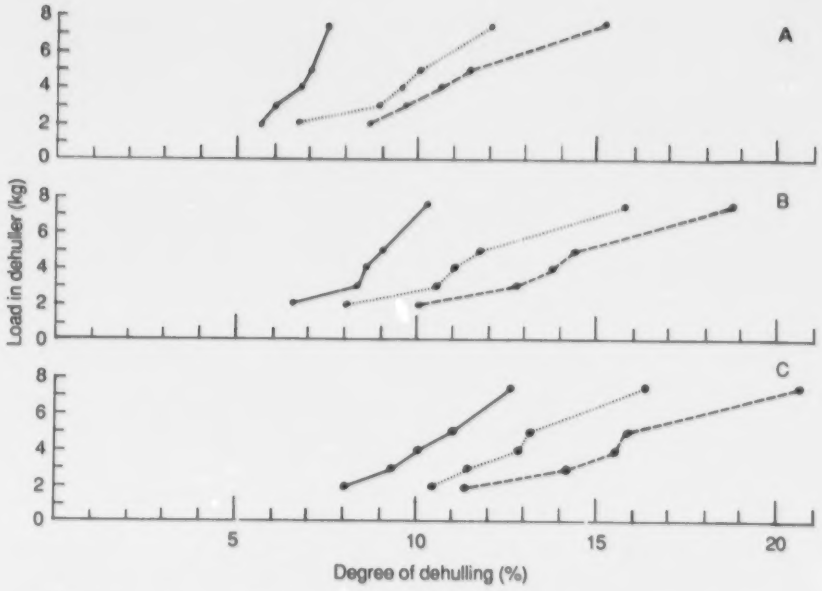

Fig. 31. Dependence of the degree of dehulling on time of dehulling (A, 3 minutes; B, 4 minutes; and C, 5 minutes) and speed of revolution (solid line, 1 500 rpm; dotted line, 1 750 rpm; and dashed line, 2 000 rpm) for the Mini-PRL dehuller (from Mbengue 1986).

on the consumer's preference and the extent of the disk wear. Dehulling times are substantially greater than these for some grains and less for some others; for example, a local grain in the Gambia called *findi* (*Digitalis exilis*), about 10% the size of sorghum, can be dehulled in about 10–15 minutes, whereas sesame seeds can be dehulled in about 1 minute using a Mini-CRS dehuller. In general, operators need to operate the dehullers at a fixed speed and to vary the time to obtain the customer's desired yield.

Price for dehulling

The cost of dehulling and grinding is crucial to the economic viability of the mill. Assuming that there are enough grains to dehull and clients to patronize the mill, the price for processing 1 kg of grain must be set using standard economic analysis that accounts for such items as capital, operating, and maintenance costs; interest rates; inflation; replacement costs of equipment; profit; and amount of grains to be processed.

Mills operated by entrepreneurs fix processing fees based on simple economics. Test data for one such mill show that the owner originally set a price for dehulling that ensured a reasonable profit. This price has been increased a few times with no long-term drop in the amount of grains processed (Schoonmaker Freudenberger 1988). We must emphasize, however, that this particular mill operates on electricity and has no competition from any other dehuller in a semiurban community.

Village mills managed by committees are, however, hesitant to levy processing fees that will ensure their viable operation. They are often under pressure to please the community and are not fully conscious of the need to plan for the replacement of equipment. These mills, therefore, tend to be operated uneconomically. Thus, efforts must be made initially to provide expert help to establish dehulling and grinding fees that would at least ensure that the basic monthly financial commitments are met.

Various schemes that have been used to charge for milling consist of:

- Setting separate prices per kilogram for dehulling and grinding;
- Setting a fixed price per kilogram whether dehulling or grinding is done; and
- Setting a price per kilogram that is related to the quantity to be dehulled, to account for the fact that smaller quantities of grain use more energy per kilogram (see Fig. 32).

Mixed results have been obtained with these pricing systems and experience shows each individual system has to be assessed at intervals and a stable price arrived at by trial and error based on user reaction.

Women must have money to pay for mechanical processing. The lack of liquidity in villages, because of very low incomes, poses a substantial obstacle to the viable operation of dehullers in each needy community. One of the main reasons women do not patronize mills is because they are unable to pay the fees charged.

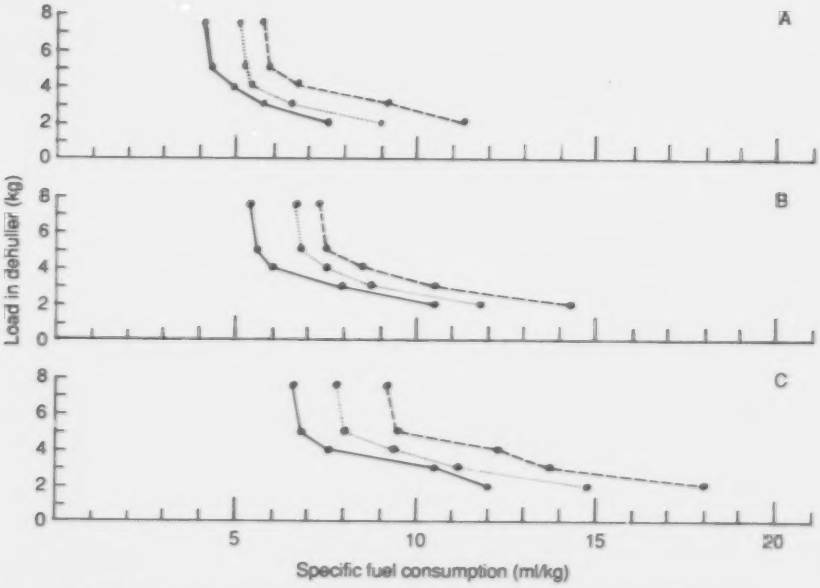

Fig. 32. Dependence of fuel consumption on time of dehulling (A, 3 minutes; B, 4 minutes; and C, 5 minutes) and speed of revolution (solid line, 1 500 rpm; dotted line, 1 750 rpm; and dashed line, 2 000 rpm) for the Mini-PRL dehuller (from Mbengue 1986).

Another factor that influences the level of processing fees is the quantity of grains dehulled. Because of, for example, climatic conditions, some mills process small quantities of grains, resulting in the need to charge more to dehull a given amount. This has resulted in processing fees being set so high that clients cannot afford them or so low that the mill is not viable. A typical range of realistic estimated costs for dehulling and grinding, for various quantities processed, is shown in Fig. 33 for mills using a Mini-CRS dehuller and a grinder with a diesel engine in the Gambia. The operating points for several village mills are also shown compared to the break-even reference point, indicating that these mills' should levy quite high processing fees to be economically viable.

Amounts of grains dehulled

Quantities dehulled per client vary between 3 and 7 kg for countries in West Africa and up to 18 kg for Zimbabwe. For this reason, the capacity of the Mini-CRS and Mini-SISMAR/ISRA dehullers are different from that of the Mini-ENDA dehuller. At the rate of processing and unloading a 6-kg load in

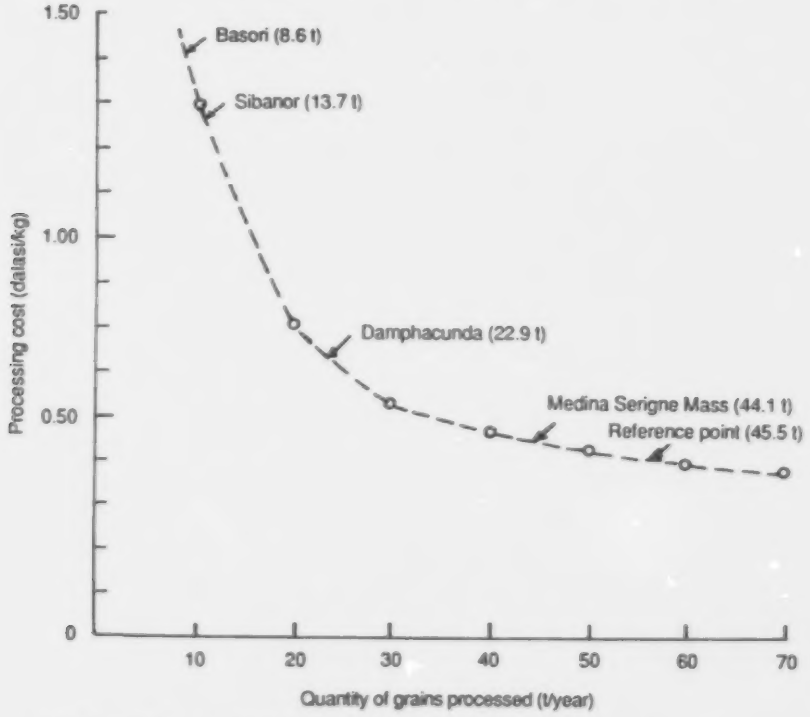

Fig. 33. Estimated cost for dehulling and grinding, for various throughputs of grain, using a CRS dehuller, hammer mill, and diesel engine (from Schoonmaker Freudenberger 1988). Points are estimated costs for an assumed throughput. Arrows indicate annual throughput in 1987 and a realistic processing cost at that level of use for various mills; reference point is the minimum throughput that will make the mill economically viable considering the availability of liquid cash in villages. (1 Gambian dalasi [GMD] = 0.1606 US dollar [USD].)

4 minutes, 600 kg of grain can be processed in 8 hours using the Mini-CRS and Mini-SISMAR/ISRA dehullers, whereas about 1 000 kg can be processed with the Mini-ENDA machine in the same period.

Typical quantities of sorghum, millet, and maize dehulled in Senegal and the Gambia using the Mini-SISMAR/ISRA I and Mini-CRS dehullers, respectively, are

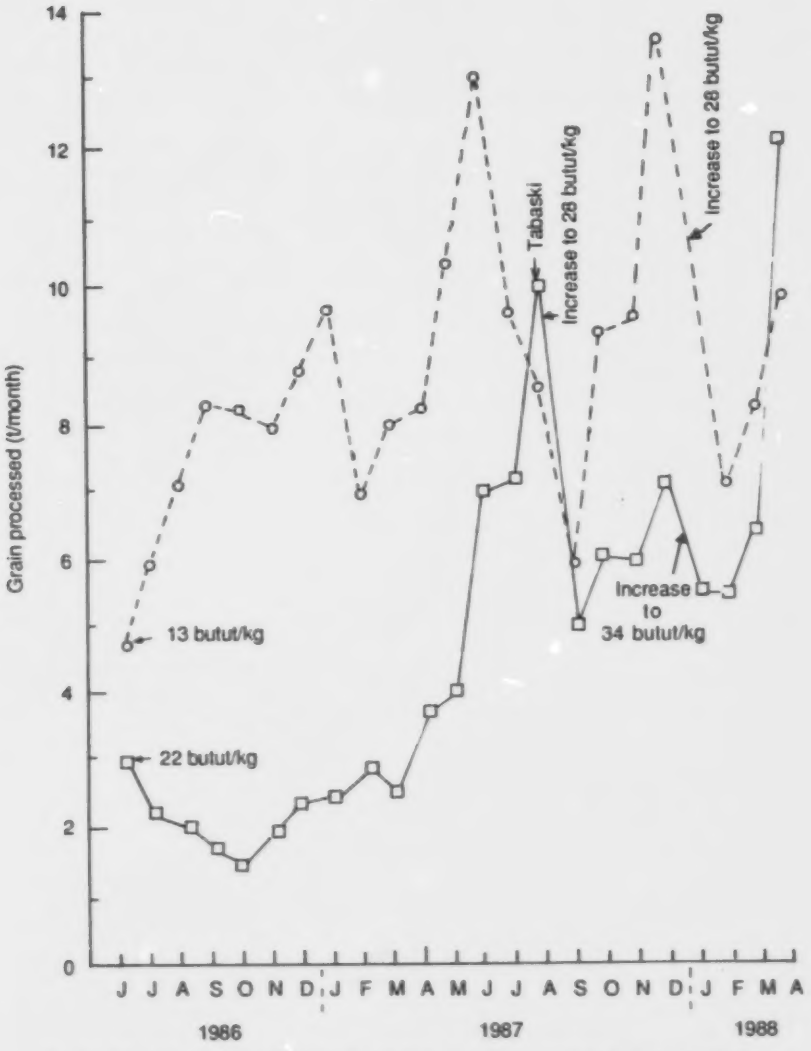

Fig. 34. Monthly throughputs for the dehuller and hammer mill at the electrically operated mill in Brikama, the Gambia (from Schoonmaker Freudenberger 1988). Solid line, dehulling; broken line, milling; tabaski is a local holiday; 100 butut = 1 GMD = 0.1606 USD.

shown in Figs 34–36. In the Gambia, for example, an electrically operated mill has processed over 24 t of grain in 365 days, with amounts processed each month ranging from 0.5 to 3.5 t. Some mills in Senegal are dehulling up to 0.5 t/day. Quantities dehulled depends on the time of the year with low throughputs being obtained before the harvesting season and around midmonth, and large quantities being processed during certain local functions, local holidays, early in the month etc. The effect of increasing dehulling fees on user reaction is shown in Fig. 34; initially, the quantity dehulled drops when the fees increase but later the quantity increases again.

The importance of the quantity of grain dehulled on the economic performance can be inferred from Fig. 32. Field tests in nine villages indicate that it is desirable to process large quantities of millet, sorghum, or maize (Table 11). Mills with larger batch sizes and higher daily throughputs have lower fuel consumption.

Use of dehullers compared with grinders

Grinders are more widely used than dehullers (Fig. 34), partly because the former have existed longer and women are accustomed to paying for this service. Abrasive-disk dehullers are new and, where other types of dehullers have been installed, they have not given satisfactory results. Another reason for lower utilization of the abrasive-disk dehullers is because some of the women prefer the

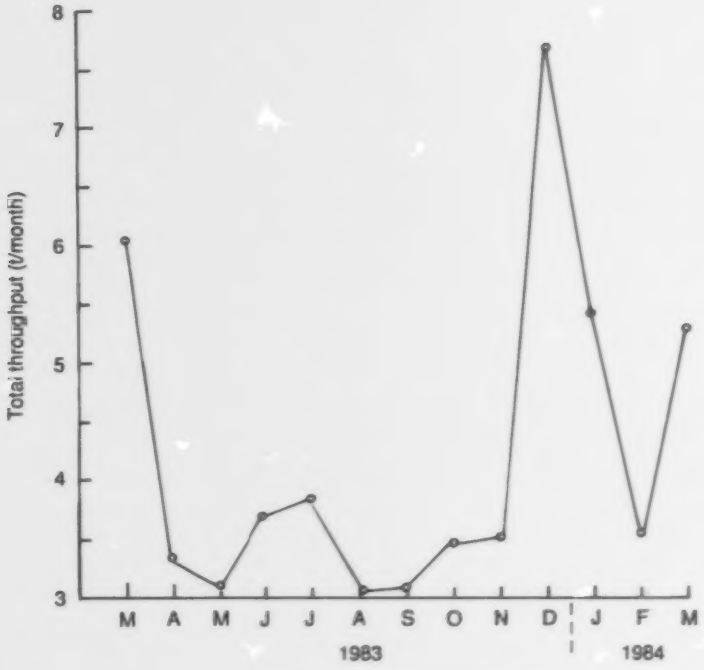

Fig. 35. Monthly throughput for a rural diesel operated mill in Damphacunda in the Gambia (from Schoonmaker Freudenberger 1988).

product of wet dehulling that gives the grain a characteristic taste. This reservation is, however, expected to diminish as the women become accustomed to machine dehulling; some clients now use the dehullers to process large quantities of grain that are stored and then water-washed to give the same taste as is produced by wet dehulling.

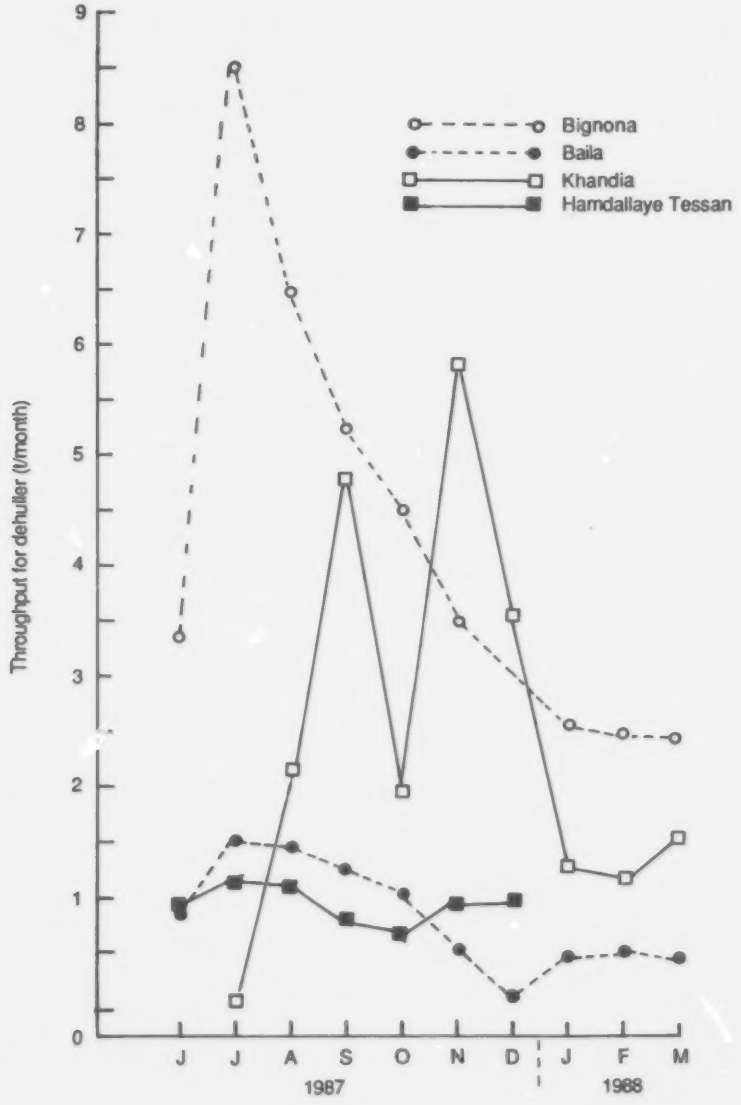

Fig. 36. Monthly throughput for the Mini-SISMAR/ISRA I dehuller used in four rural, diesel-operated mills (from Mbengue 1988).

Table 11. Effect of daily throughput on fuel consumption for mills using the Mini-SISMAR/ISRA I dehuller.

Location	Population	Mean specific fuel consumption (mL/kg)	Mean daily throughput (kg/day)	Total quantity dehulled over 10-month period (kg)
Baila	1 400	20.41	34	8 378
B. Tialene	1 700	13.84	64	13 151
Bignona	25 000	12.51	179	42 122
Hamdallaye Tessan	1 000	18.83	38	7 114
Kartiack	2 300	24.77	22	4 982
K.S. Kane	3 700	16.93	96	18 195
Khandiar	700	10.15	145	22 561
Lambaye	5 000	14.40	34	8 056
Mont Roland	5 000	15.81	30	4 288

Source: Mbengue (1988).

It has recently been proposed (Schoonmaker Freudenberger 1988) that women may regard mechanical grinding as a cost-saving activity; some women stated that machine grinding gives more flour compared with traditional pounding. Because of the higher priority given to grinding and the comment that dehullers give grains that are difficult to hand pound, a grinder should be installed with an abrasive-disk dehuller.

Maintenance and spare parts

Maintenance plays an important role in the operation of mills. For an electrically powered mill, maintenance is limited to periodic dusting of machines, tightening bolts, and replacing worn disks in the dehullers. Diesel engine-powered mills, however, need much more attention. In addition to cleaning to prevent bran and flour dust from affecting engine performance, basic maintenance for diesel engines should be completed as specified in operation manuals. Over 90% of the down-time in these mills are because of engine faults resulting from poor maintenance by mill operators. Repairs, and hence down-time, are frequent in mills that experience substantial vibration from the engine because the dehullers and grinders tend to develop cracks, parts become loose, and V-belts become stretched or worn.

Lack of spare parts is a potential threat to the successful operation of mills. Parts such as abrasive disks, bearings, and diesel-engine spares should be available locally, but this is not often the case. It has been found useful for manufacturers of the dehullers to stock a reasonable quantity of spares that can be bought by mill operators. Abrasive disks are available in some main cities but the surface specification may not be that recommended. Efforts should, therefore, be made by mills to stock a reasonable quantity of spare parts and to replenish this as the stock diminishes, taking into account the economic advantages of doing so.

Disk life and dehuller performance

There are, at present, no conclusive and detailed data on the life of various types of abrasive disks (grinding stones and lightweight disks). However, village testing

in Senegal using the Mini-SISMAR/ISRA I dehuller has produced substantial results that indicate that the life of the disks (degree of wear) depends on the quantity of grain dehulled in each batch. Disk wear was compared (Table 12) for machines located at Bignona, Khandiar, and Hamdallaye Tessan after dehulling 24, 21, and 4 t of grain respectively (Mbengue 1988).

The Bignona and Khandiar mills process larger quantities of grains than that at Hamdallaye Tessan (Table 12) and process batches larger than 6 kg whereas the third mill processes batches of 2–3 kg. The diameter, thickness, and mass for all the 10 disks in each dehuller, as well as mean values, clearly show that, although the Hamdallaye Tessan mill processed less than 20% of the amount processed by the other two, this mill had substantially more wear in disk diameter and mass. Such differences in wear have been explained by Mbengue (1988): small batches of grain in the dehuller are processed by the edges of the disks, which become worn, whereas the larger batches are dehulled by more of the disks' surfaces, thus reducing wear at their edges. It is, therefore, more cost effective to operate the dehullers with their barrels full.

These field test results were the basis for the development of the Mini-SISMAR/ ISRA II dehuller with the twin compartment so that each chamber can be operated full with a 3- to 4-kg batch of grains, thus optimizing the use of power and reducing the wear on the abrasive disks.

Evaluation of Dehuller's Performance and Impact

Improvements in the performance of the mill can only be obtained by evaluating its overall performance and its effect on the users. Both technical and socioeconomic data collected over at least 1 year are needed for such an assessment. Persons responsible for introducing the dehuller will need to maintain close contact with the mill staff, management committee, and users to be informed of the efficiency of the overall system of operation.

The evaluation of the mill can be facilitated by arranging for records to be kept of quantities of grain dehulled and flour produced, fuel or electric power used, maintenance costs, and frequency of breakdowns. Through interviews before, during, and after a specified period, which should not be less than 1 year, various factors related to the socioeconomic impact of the mill on the population could be assessed. Some of the questions to which answers would need to be provided by an interdisciplinary team, consisting of social scientists and technologists, are:

- What is the quality of the product and how consistently does the mill produce it?
- How difficult or easy is it to operate the mill?
- What is the frequency of breakdowns and what causes them?
- How often do the abrasive disks have to be changed? How does their wear affect the efficiency of the mill?
- What is the consumption of energy per unit weight of processed grain?
- What quantities of grain are processed daily, weekly, monthly, and on a seasonal basis?

Table 12. Wear experienced by resinoid disks at three village mills in Senegal.

Disk number	Bignona (24 t dehulled)			Khandiar (21 t dehulled)			Hamdallaye Tessan (4 t dehulled)		
	Diameter (mm)	Thickness (mm)	Mass (g)	Diameter (mm)	Thickness (mm)	Mass (g)	Diameter (mm)	Thickness (mm)	Mass (g)
1	229	34	287.6	240	28	275.0	202	31	215.4
2	230	32	275.1	243	28	300.0	159	30	130.9
3	232	33	299.7	242	29	300.0	164	33	142.7
4	233	33	295.7	243	29	296.0	162	33	140.0
5	230	32	289.1	243	29	303.4	166	33	149.9
6	235	30	287.1	244	31	330.3	174	33	163.4
7	225	31	246.2	243	30	305.2	174	33	162.6
8	228	32	274.3	243	29	308.2	175	34	167.6
9	228	30	266.4	240	28	280.8	180	35	180.2
10	224	31	249.0	243	30	306.0	227	32	278.1
Average	229.4	31.8	277.0	242.4	29.1	300.6	178.3	32.7	173.1
% wear[a]	9.7	11.7	25.2	4.6	19.2	18.8	29.8	9.2	53.3

[a] With respect to new disks: diameter = 254 mm; thickness = 36 mm; mass = 370.3 g.

- What is the average weight of grain dehulled per customer?
- Is the mill making a fair profit?
- What is the trend in the number of clients who dehull grains?
- What, in the users' opinions, are the benefits of the mill?
- What are the changes in food preparation, eating habits, and nutritional status of the people?
- How do the women use the time released by using the mill? and
- What social or economic changes are associated with the presence of the mill?

As experience is gained in mill operations, more information will be available to allow case studies to be documented. Using these case studies, future mills can be properly planned and operated.

CHAPTER 7
MOVING FROM RESEARCH TO DISSEMINATION

This final chapter returns to the issues raised in the book's introduction by summarizing the range of problems for which the technology discussed is a potential solution. Two figures are presented, both of which characterize the prevailing sorghum and millet food system and show how the system can be affected by intervening with the small-scale dehuller hardware. Next, we analyze the steps necessary to achieve successful research-for-development. Finally, the role and responsibilities of the applied researcher in wider dissemination of technology is examined.

RANGE OF USEFULNESS OF DEHULLERS

The collective experiences to date lead to the conclusion that dehullers can have a significant role in the food systems of sorghum and millet in sub-Saharan Africa. Many factors define the extent of that role, and many are under the control of those who determine national policies on food, agricultural production, and household food security.

Abrasive-disk dehullers are strong contenders as solutions for problems where:

- Women and children daily devote much labour-intensive time to manually processing their grain before it can be consumed;
- Food preferences favour those cereal grains that do not grow well in the dry areas, and where the absence of appropriate processing machinery contributes to an impoverishment of indigenous dryland agriculture; and
- Antinutritional components, polyphenols, in the grain have not been fully removable with traditional processing techniques; this has probably resulted in a lowered nutritional status, especially for the segment of the population that is most at risk.

Evidence from applied research indicates that dehullers are technically capable of contributing to the solution of these three problems. The next section presents one analysis of the sorghum and millet food system, and identifies the possible points at which one can intervene to improve that food system.

EFFECT ON THE FOOD SYSTEM OF A TECHNOLOGY INTERVENTION

Although it is understood that Africa is in the middle of rapid social change, of which growing urbanization is a major facet, the reader is reminded of two important facts:

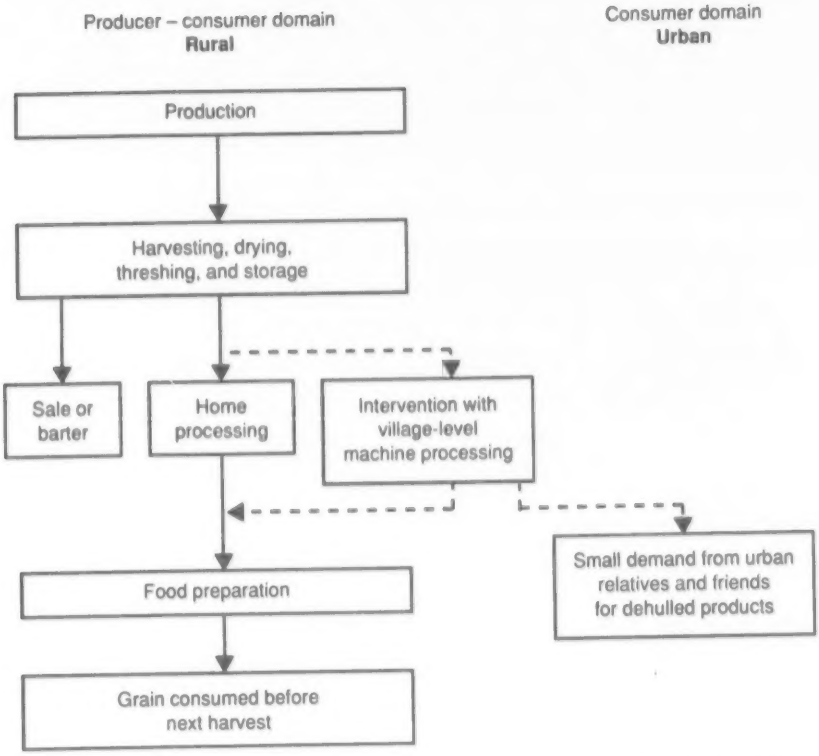

Fig. 37. Effect on food systems by introduction of rurally located dehulling machinery.

- 80% of Africa's population is still located in the rural areas, relies heavily on subsistence agriculture for its continued survival, and is relatively poor; and
- A substantial portion of the food produced remains on the farm for consumption by rural households. This is especially true of the small grains, sorghum and millet, which lack demand for surplus production.

The definition and description of a food system is inextricably tied to the people who eat that food and to their environment. People living in the semi-arid areas, and dependent on drought-resistant sorghum and millet, are part of the producer–consumer domain. Similarly, one might define urban dwellers as belonging to the domain of consumers who are not food producers.

The concept of these two domains is used in Figs 37 and 38 to suggest a possible scenario for applying dehuller technology at two different intervention points. In the specific case of the neglected sorghum and millet, the figures represent deliberate sequential interventions, first in the producer–consumer domain and then in the domain of the consumer who is not a producer.

The provision of dehullers to the rural areas is indicated in Fig. 37. The predicted major effect is the easing of a labour bottleneck in individual households,

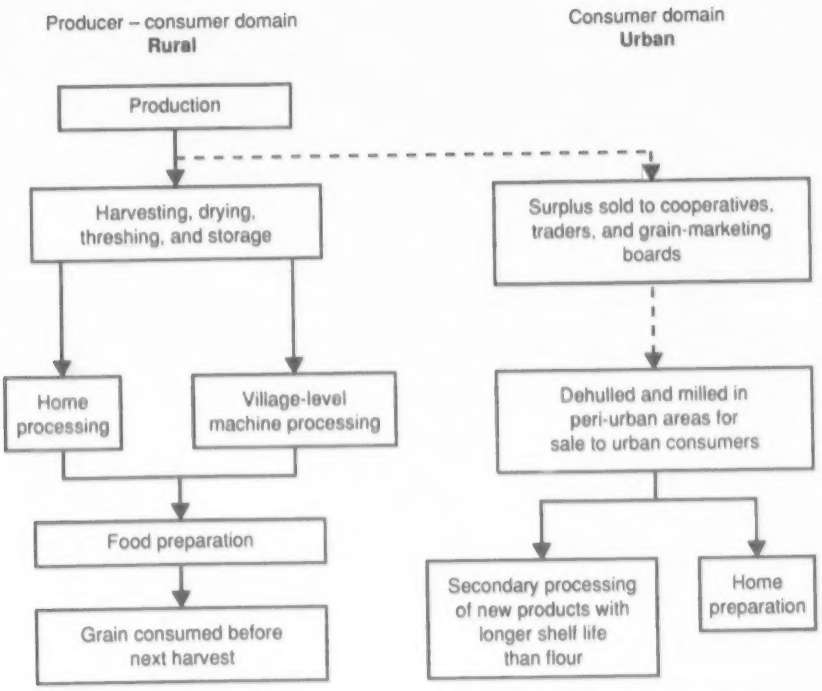
Producer – consumer domain
Rural
Consumer domain
Urban
Production
Harvesting, drying, threshing, and storage
Surplus sold to cooperatives, traders, and grain-marketing boards
Home processing
Village-level machine processing
Dehulled and milled in peri-urban areas for sale to urban consumers
Food preparation
Grain consumed before next harvest
Secondary processing of new products with longer shelf life than flour
Home preparation

Fig. 38. Development of food system for sorghum and bulrush millet when surplus is available.

thus contributing to an increase in the quality of rural life. Initially, the existence of the dehullers will be little noticed by urban areas, but most likely by relatives and friends of the rural dwellers. These urban dwellers may be attracted by the availability of the processed, ready-to-cook product, but may not be numerous enough to cause a major demand for surplus production of the drought-resistant grains.

Figure 38 reflects the changes that might be expected if intervention with the dehuller technology in urban or peri-urban areas is coupled with a responsive grain-marketing strategy. Urban access to ready-to-cook forms of sorghum and millet, if competitively priced, can generate a sustained demand for surplus production. This demand can then be met by adding mechanisms to facilitate purchase and transport of the grain or processed products from rural areas to the towns.

The critical reader will understand the many assumptions that these figures contain, and will also appreciate that the sequential technology interventions are not impossible to achieve, especially if the policy climate has been adjusted to encourage the desired changes: rural and urban employment in small-scale mills, favourable producer prices, etc.

It is a matter of national choice, of priorities and of opportunities recognized, whether the applied researcher focuses first on the producer–consumer domain, on both domains at once, or on the domain of the consumer who is not a producer. In each choice made, there will be those who gain and those who lose as a result of

technological intervention. One strategic approach is to minimize the impact of the loss and to distribute the gains as widely as possible. The applied researcher will have a clear opportunity to provide the policymaker with options and an analysis of the consequences of each option, and to enlist the policymaker's support for an effective intervention.

TECHNOLOGY DEVELOPMENT IN RESPONSE TO USER NEEDS

The strategy underlying the research support has been to emphasize and encourage:

- Identification and characterization by national scientists of the precise nature of the food problem;
- Development of technical solutions by scientists working hand-in-hand with the intended beneficiaries;
- Small-scale solutions that respond to rural needs;
- Solutions that are capable of rural operation and maintenance and that are capable of manufacture on the continent; and
- Targeting research-for-development rather than research for its own sake.

A successful process of research-for-development usually contains the following four steps:

- First, identifying or recognizing a widespread problem or opportunity;
- Second, generating a technology (by invention, adaptation, or adoption) that is likely to solve that problem;
- Third, confirming, in concert with the intended beneficiary, that the technology is technically sound, economically viable, and socially acceptable; and
- Fourth, taking the necessary steps to bring the solution — the technology — into widespread use.

A more rigorous presentation of these four steps, including critical feedback loops for checking the continued correctness of earlier assumptions or hypotheses, is depicted in Fig. 39 (Bassey and Schmidt 1987). The flowchart emphasizes problem identification and regularly querying whether the problem has been correctly characterized or described. It emphasizes early (laboratory-based) testing of a prototype for its technical performance, followed by testing the prototype for social acceptability and economic viability in partnership with the intended beneficiary under "real-life" conditions. The next step, replicating this test in a variety of user domains, will reveal whether there is a wider, effective demand for the technology. If the answer is yes, then one is ready to plan for wider-scale dissemination of the technology.

ROLE OF THE APPLIED RESEARCHER IN DEHULLER POPULARIZATION

Further reflection on Fig. 39, and the four-point sequence that preceded it, leads to the following comments and observations.

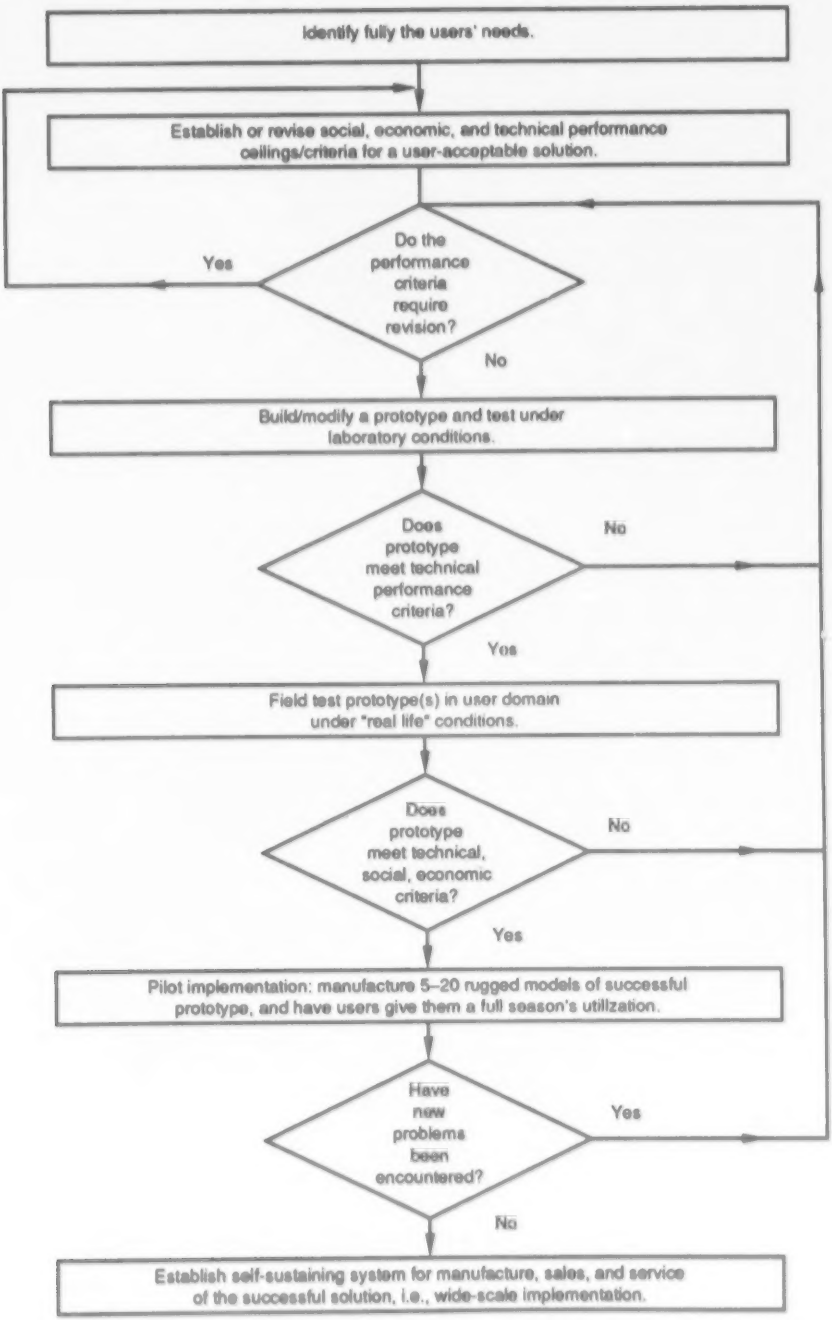
Identify fully the users' needs.
Establish or revise social, economic, and technical performance ceilings/criteria for a user-acceptable solution.
Do the performance criteria require revision?
Yes
No
Build/modify a prototype and test under laboratory conditions.
Does prototype meet technical performance criteria?
No
Yes
Field test prototype(s) in user domain under "real life" conditions.
Does prototype meet technical, social, economic criteria?
No
Yes
Pilot implementation: manufacture 5–20 rugged models of successful prototype, and have users give them a full season's utilization.
Have new problems been encountered?
Yes
No
Establish self-sustaining system for manufacture, sales, and service of the successful solution, i.e., wide-scale implementation.

Fig. 39. The applied research process for technology development in response to user needs (from Bassey and Schmidt 1987).

The applied scientist is usually confident with the second of the four steps and tends to focus on that step, often to the exclusion of the others. She or he is often most comfortable in a laboratory setting and expresses the feeling that the necessary experiments in step 3 provide an environment in which too many factors are uncontrollable. Rather than accepting the challenges of that environment as the ultimate test of the usefulness of the research efforts, the researcher tends to retreat to the controllable environment of the laboratory. The applied scientist also tends to feel that step 1 and parts of step 3 fall much more into the domain of the social scientists and wishes to have little or nothing to do with those aspects. Similarly, step 4 is often viewed as the exclusive domain of the (often nonexistent or understaffed) extension service, or of industry.

Such attitudes are commonly encountered. They are also justifiable in the light of the primary training that the applied scientist has received. However, these interpretations must also be viewed as constraints to achieving a complete research-for-development process. Can these constraints be overcome?

Seldom does one researcher have the requisite skills or the interest to single-handedly complete the total process of research-for-development. However, the researcher can co-opt other disciplines to form a team.

The applied research team, which has accrued experience with an abrasive-disk dehuller, is in a position to promote dehuller dissemination by interpreting and targeting the research results toward the following:

- Rural development or extension agencies — the researchers can document the opportunity for creating jobs in the rural areas with small-scale processing ventures;
- Credit agencies — the researchers can demonstrate the profitability of a rural mill and show that a loan for equipment purchase can be repaid;
- Metal-working establishments — the researchers can point to a rugged design that can be manufactured locally and for which a potential demand can be demonstrated;
- Policymakers — the researchers can demonstrate that a policy favouring rural food processing is worth formulating and can be implemented;
- Agricultural ministries — the researchers can show that the home-processing bottleneck can be eliminated, thus providing key technical complementarity to extension efforts directed at increasing the planting of sorghum and millet in the semi-arid areas; the researchers' findings will also contribute to the effectiveness of agricultural research by providing the improvement team with important criteria concerning how easily the different varieties commonly being planted can be processed.

An effective transfer of technology requires far more than mere transfer of hardware. By ensuring that applied research is conducted systematically and that the results of research are selectively aimed at national colleagues who share the responsibilities for national development, national food self-sufficiency, and household food security, the researchers will indeed be engaged in meaningful and useful transfer of technology. Skilled human resources are still scarce in the region, and their wise and effective deployment is critical to Africa's future.

APPENDIX A
DEFINITION OF TERMINOLOGIES

In March 1985, IDRC hosted a workshop on "Technical Aspects of Dehullers." Researchers from African countries, both francophone and anglophone, shared their experience, frustrations, and successes, and decided to define some of the words that have led to miscommunication at times.

Dehulling (décorticage) is the process of removing a portion or all of the outside layer(s) of the grain. Thus, the machine is a *dehuller* (décortiqueur). Care must be taken to understand that the term dehuller when applied to rice defines a machine that both dehusks and debrans. The dehulling machinery described in this book is not an effective rice dehusker, but more a debranner.

Dehuller performance can be measured in several ways. A dehuller performs a processing action on a quantity of grain *input*, which results in *output* (a weight of dehulled material) and *bran* (powdery material) or abraded fines.

- *Yield* is therefore (output/input) × 100.

Hourly performance of a machine can be reported variously as:

- *Throughput* (capacité): kilograms of grain per hour entering the dehuller (input); or
- *Output* (productivité): kilograms of dehulled grain per hour leaving the dehuller.

Glume is a leafy portion that often adheres to a sorghum kernel; its presence is the result of incomplete threshing, and it is removed in a dehuller.

Grinding or *pulverizing* (mouture, broyage) is the process of reducing an intact kernel of grain into smaller, coarse or fine, particles. In English, the term milling usually refers to the act of grinding or pulverizing.

The primary processing most commonly done to cereal grains and grain legumes is to reduce the grains, by one step or several stages, to a flour form. The physical plant in which this is accomplished mechanically is given the term *mill* (minoterie). Synonyms are grain-processing system or dehulling–grinding system (système de traitement–transformation).

Pericarp (péricarpe) is defined by plant scientists and cereals technologists as the outermost portion of the intact sorghum or millet kernel. An equivalent term is hull layers. The pericarp, when carefully separated from the remainder of the kernel, represents 3–10% of a sorghum grain's weight. At this level of "precision," the whole kernel of grain can be defined as consisting of three parts: pericarp, endosperm, and germ.

Yield (rendement) is the percentage by weight of kernel material that remains after a dehulling process:

- [(Original weight – dehulled kernel weight)/original weight] × 100; or
- (Output/input) × 100;
- *theoretical yield* = 100 – % by weight of pericarp.

Extraction rate (taux d'extraction) is that level of yield that meets a predetermined acceptability test; i.e., *acceptable yield* (rendement acceptable). Laboratory scientists have used colour measurements of resulting flour, percentage tannin by weight, and percentage fibre by weight to define extraction rate. In practice, the person doing the pounding has a subjective visual measure of acceptable yield, and stops pounding when she judges this measure to have been achieved. The term extraction rate has been loosely used in the literature as a synonym for yield, rather than for acceptable yield.

Power consumption of the system must be defined. Researchers should not only record the rated power of the engine (horsepower; 1 hp = 746 W) or of the electric motor (kilovolt-ampere, kVA) but also report indicative figures of how many litres of diesel fuel are required to process 1 kg of input, or of how many kilowatt-hours of metered electricity are required.

The abrasive action in these dehullers is provided by circular disks or wheels — *disk* (disque), *stone* (meule), or *grinding wheel* — mounted on a shaft and separated from each other by spacers. We use the term disk to indicate this disk-shape or wheel-shape. The grinding wheels used are of the type used in industry to sharpen tools. These are often commonly referred to as stones, grinding stones, or grinding wheels. Alternatively, resinoid disks, used by industry for cutting metal, have been used as the abrasive disks.

APPENDIX B
GRINDING STONE SPECIFICATION

The key identifiers for specifying grinding stone composition are type of abrasive, grit size, grade, structure, and bond (Norton Company 1975). Different manufacturers may use different numerical or alphabetic codes.

Types of abrasive commonly used are silicon carbide and aluminum oxide, which can have varying degrees of purity and different wear and fracture characteristics.

Grit size is indicated by the mesh of the smallest sieve through which the grit can pass. Commonly, the mesh size ranges from 10 (coarse) to 220 (very fine). For some applications, a mixture of grit sizes (e.g., one-third each of 80-, 60-, and 46-grit) is desired.

Grade indicates the relationship between the quantity of bonding material and grit material. Grade A contains little bonding material and, as a result, the grit dislodges easily and the wheel is rated as being "soft." Grade Z contains a maximum of bonding material, the grit is held very firmly, and the wheel has a "hard" rating.

Structure indicates the relationship of abrasive to bonding material and the relationship of these two elements to the air spaces or voids that separate them. A rating of 0 is dense; a rating of 12 is open. Structure, therefore, seems to refer to the amount of compression under which the wheel is moulded.

Different *bonding* materials exist, but tend to be considered as proprietary information by manufacturers. Basic types of bond are identified as vitrified (V), resinoid (B), rubber (R), and shellac (E). The vitrified bond consists of feldspar and clays selected for their ability to fuse together. A further code indicates different types of bond modifications used.

A *typical specification* by the Norton Company (1975) is:

A	36	L	5	V	BE
Abrasive type	Grit size	Grade	Structure	Vitrified bond	Modification

RIIC selected as its abrasive disk the grinding stone with the Norton Specification of 37C 60 Q V K. The abrasive type is silicon carbide of the less pure grade. It is described as black, durable, and used in rough metal-grinding applications. (By contrast, 39C is pure silicon carbide, green in colour, and friable (it breaks off easily), it tends to be used in precision metal applications.) The grit code of 60 means that equal amounts of 80-, 70-, and 60-grit abrasive size was used — to have 100% 60-grit, the number 601 would be specified. The grit code number 543 indicates equal portions of 46-grit and of 60-grit. The grade of Q is for a wheel with a medium to hard rating. When no structure number is given, as in this case, a rating of five is assumed, that being used for general purpose wheels. The bond V indicates the nontoxic vitrified bond. Bond modification K gives a milder grinding action.

Further specification for the *surface dressing* of the side faces is desirable: V-faced is a rough finish achieved by a ball-peening process, "ground" indicates dressing done by a grinding (dressing) stone, leaving a smooth finish.

Appendix C

Some institutions undertaking dehuller research

Botswana

Rural Industries Innovation Centre, Private Bag 11, Kanye, Botswana

Botswana Mill Owners Association, PO Box 483, Gaborone, Botswana

Canada

Plant Biotechnology Institute, National Research Council of Canada, 110 Gymnasium Road, Saskatoon, SK, Canada S7N 0W9

Nutana Machinery, 2615 First Avenue North, Saskatoon, SK, Canada S7K 6E9

Ethiopia

Ethiopia Nutrition Institute, PO Box 5654, Addis Ababa, Ethiopia

Sorghum Improvement Programme, Institute of Agricultural Research, Nazret Research Station, PO Box 103, Nazret, Ethiopia

Institute of Development Research, Addis Ababa University, PO Box 1176, Addis Ababa, Ethiopia

France

Laboratoire de technologie des céréales, CIRAD/IRAT ENSAM, 9, place Pierre Viala, 34060 Montpellier, France

Gambia

Catholic Relief Services, PO Box 569, Banjul, Gambia

Ghana

Food Research Institute, PO Box M 20, Accra, Ghana

India

Grain Quality Laboratory, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP, India

College of Home Science, Andhra Pradesh Agricultural University, Hyderabad 500 030, AP, India

Kenya

Kenya Industrial Research and Development Institute, PO Box 30650, Nairobi, Kenya

Department of Food Technology and Nutrition, University of Nairobi, PO Box 29053, Kabete, Kenya

Lesotho

Division of Agricultural Research, Ministry of Agriculture, PO Box 829, Maseru, Lesotho

Malawi

Farm Machinery Unit, Chitedze Agricultural Research Station, PO Box 158, Lilongwe, Malawi

Mali

Section de recherche sur les cultures vivrière et oléagineuses, Division de la recherche agronomique, Institut d'économie rurale, Ministère de l'agriculture, BP 34, Bamako, Mali

CEEMA, Division du machinisme agricole, Directionale de génie rural, Ministère de l'agriculture, BP 155, Bamako, Mali

Niger

Institute for the Study and Application of Integrated Development, BP 2821, Niamey, Niger

Senegal

Centre national de la recherches agronomiques de Bambey, Institut sénégalais de recherches agricoles, Ministère de la recherche scientifique et technique, Bambey, Sénégal

Institut de technologie alimentaire, Ministère de la recherche scientifique et technique, BP 2765, Dakar, Sénégal

Société industrielle sahelienne de mécaniques, de materiels agricoles et de représentations, BP 3214, Dakar, Sénégal

Sudan

Food Research Centre, Shambat, Khartoum North, Sudan

Tanzania

Small Industries Development Organization, PO Box 2476, Dar es Salaam, Tanzania

Department of Food Science and Technology, Sokoine University of Agriculture, PO Box 3006, Morogoro, Tanzania

Tanzania Food and Nutrition Centre, PO Box 977, Dar es Salaam, Tanzania

Uganda

National Research Council, PO Box 6884, Kampala, Uganda

United Kingdom

Cereals Technology Section, Overseas Development Natural Resources Institute, Culham, Abingdon, Oxon, 0X14 3DA, UK

Zambia

Small Industries Development Organization, PO Box 35373, Lusaka, Zambia

Food Technology Research Unit, National Council for Scientific Research, PO Box CH 158, Chelston, Lusaka, Zambia

Zimbabwe

Silveira House, PO Box 545, Harare, Zimbabwe

Environment Development Activities–Zimbabwe, PO Box 3492, Harare, Zimbabwe

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* Two publications by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) are cited several times in this list. Institutions in developing countries are encouraged to request copies from ICRISAT. ICRISAT also offers a regular update of their accessions and reprint service to scientists through SATCRIS (Semi-Arid Tropical Crops Information Service), and tailor this to individual interest profiles. Write to SATCRIS SDI Service, ICRISAT, Patancheru, AP 502 324, India.

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Acronyms

ATI	Appropriate Technology International
BAMB	Botswana Agricultural Marketing Board
CIDA	Canadian International Development Agency
CNRA	National Agronomic Research Centre in Bambey (Centre national de recherches agronomiques)
CRS	Catholic Relief Services
EEC	European Economic Community
ENDA	Environment Development Activities, Zimbabwe
ENI	Ethiopia Nutrition Institute
EPOC	Equity Policy Center
FAO	Food and Agriculture Organization of the United Nations
FRC	Food Research Centre
IAR	Institute of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDR	Institute of Development Research
ISRA	Institut sénégalais de recherches agricoles
KIRDI	Kenya Industrial Research and Development Institute
NGPC	National Grains Production Company
NRCC	National Research Council of Canada
ODNRI	Overseas Development Natural Resources Institute (formerly TDRI)
PBI	Plant Biotechnology Institute (formerly PRL)
PFP	Partnership for Productivity
PRL	Prairie Regional Laboratory (now PBI)
RIIC	Rural Industries Innovation Centre
SATCRIS	Semi-Arid Tropical Crops Information Service
SIDO	Small Industries Development Organization
SISMAR	Société industrielle sahélienne de mécaniques, de matériels agricoles et de représentations
TADD	tangential abrasive dehulling device
TDRI	Tropical Development and Research Institute (now ODNRI)
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa

Head Office
IDRC, P.O. Box 8500, Ottawa, Ontario, Canada K1G 3H9

Regional Office for Southeast and East Asia
IDRC, Tanglin P.O. Box 101, Singapore 9124, Republic of Singapore

Regional Office for South Asia
IDRC, 11 Jor Bagh, New Delhi 110003, India

Regional Office for Eastern and Southern Africa
IDRC, P.O. Box 62084, Nairobi, Kenya

Regional Office for the Middle East and North Africa
IDRC/CRDI , P.O. Box 14 Orman, Giza, Cairo, Egypt

Regional Office for West and Central Africa
CRDI, B.P. 11007, CD Annexe, Dakar, Senegal

Regional Office for Latin America and the Caribbean
CIID, Apartado Aéreo 53016, Bogotá, D.E., Colombia

Please direct requests for information about IDRC and its activities to the IDRC office in your region.